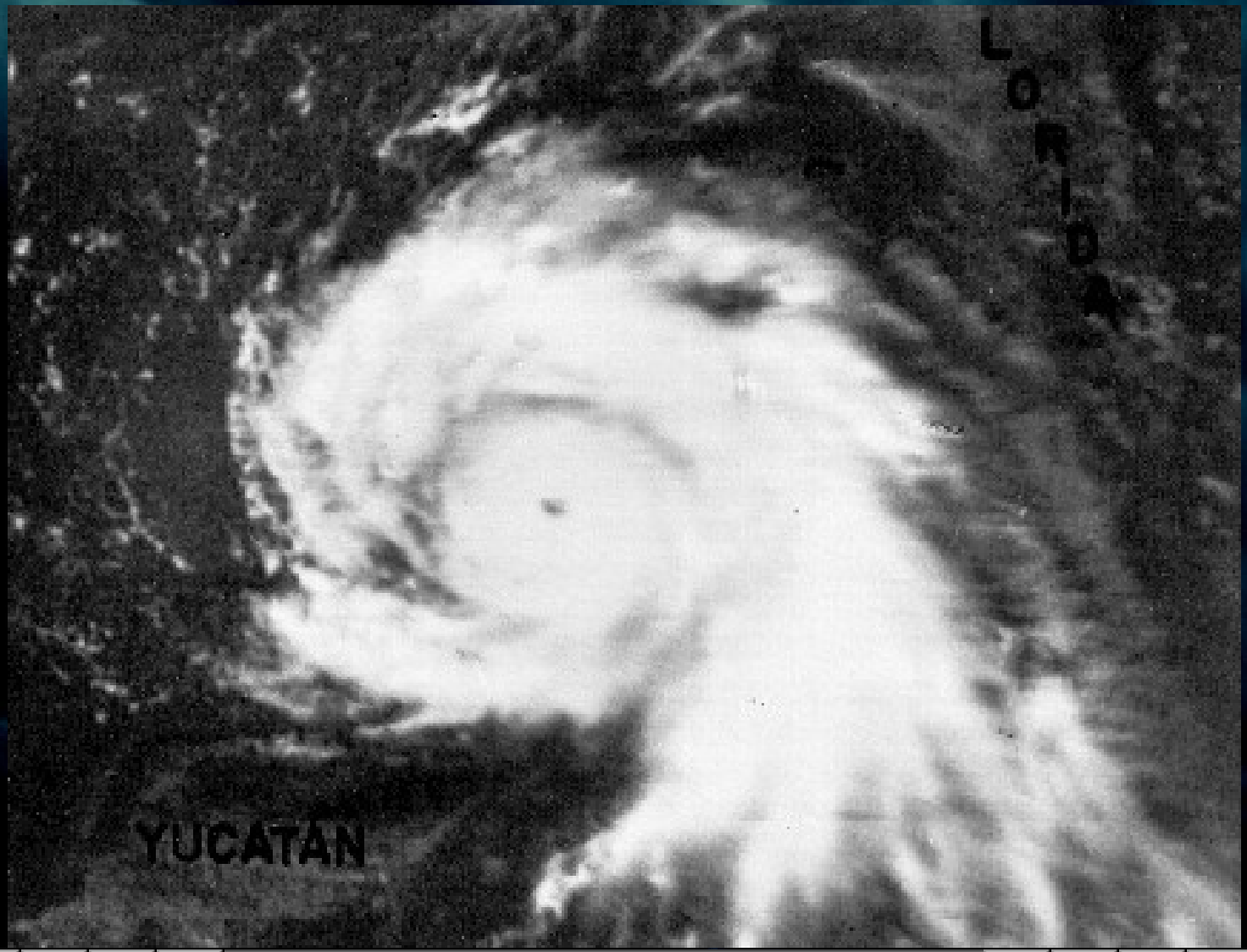
Satellite Analysis

2a. Determine system capabilities and viewing considerations of satellite imagery.

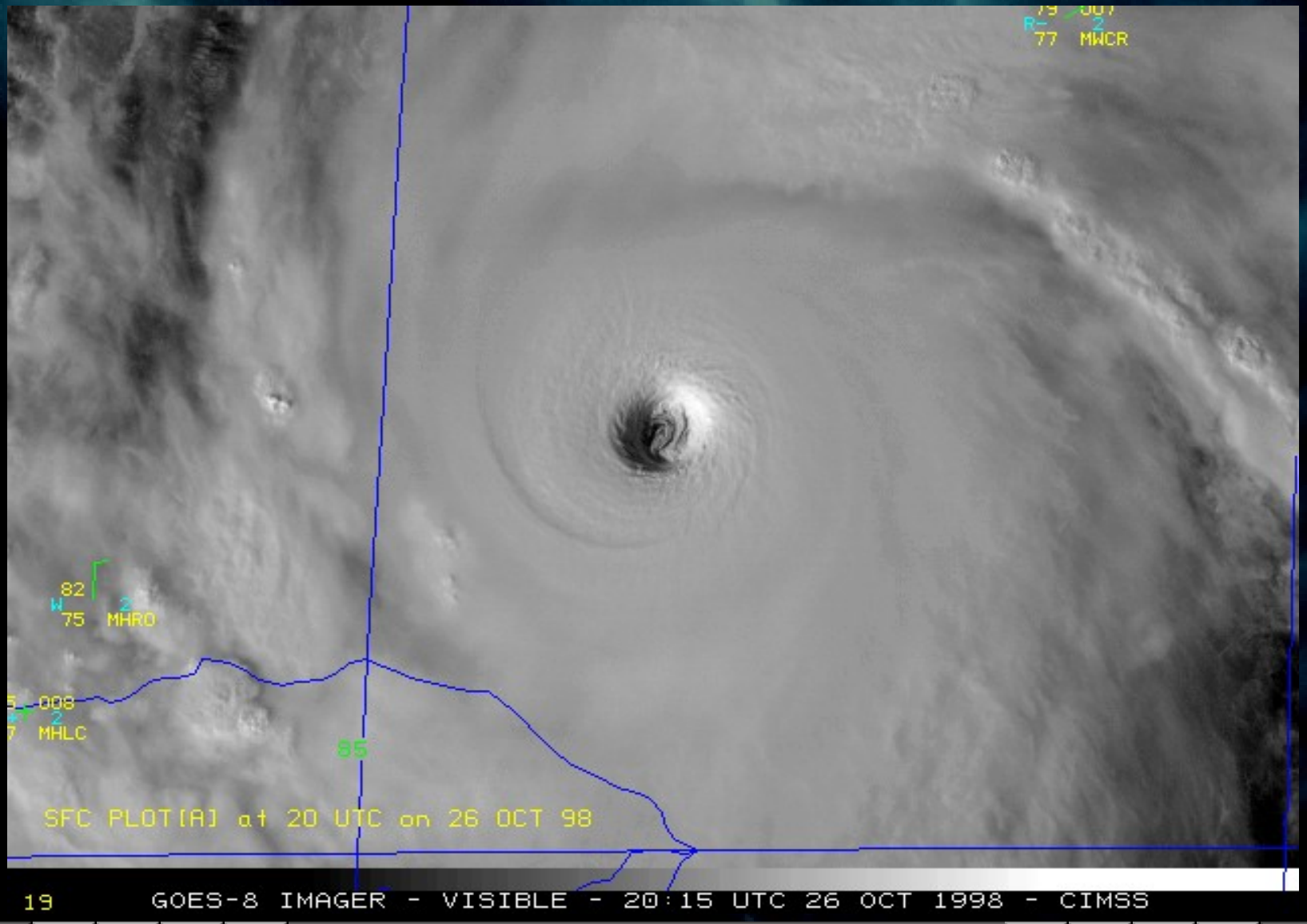
Advantages and Disadvantages of Satellite Imagery

- Availability
- Resolution
- Interpretation

Camille



Mitch


77 MWCR
82
75 MHRO
MHLC
85
SFC PLOT[A] at 20 UTC on 26 OCT 98
19 GOES-8 IMAGER - VISIBLE - 20:15 UTC 26 OCT 1998 - CIMSS

Advantages and Disadvantages of Satellite Imagery

- Advantage
  - Invaluable data source
  - Availability (vs. rawinsonde data)
  - Uniform coverage (helps in data sparse areas)
  - Better resolution

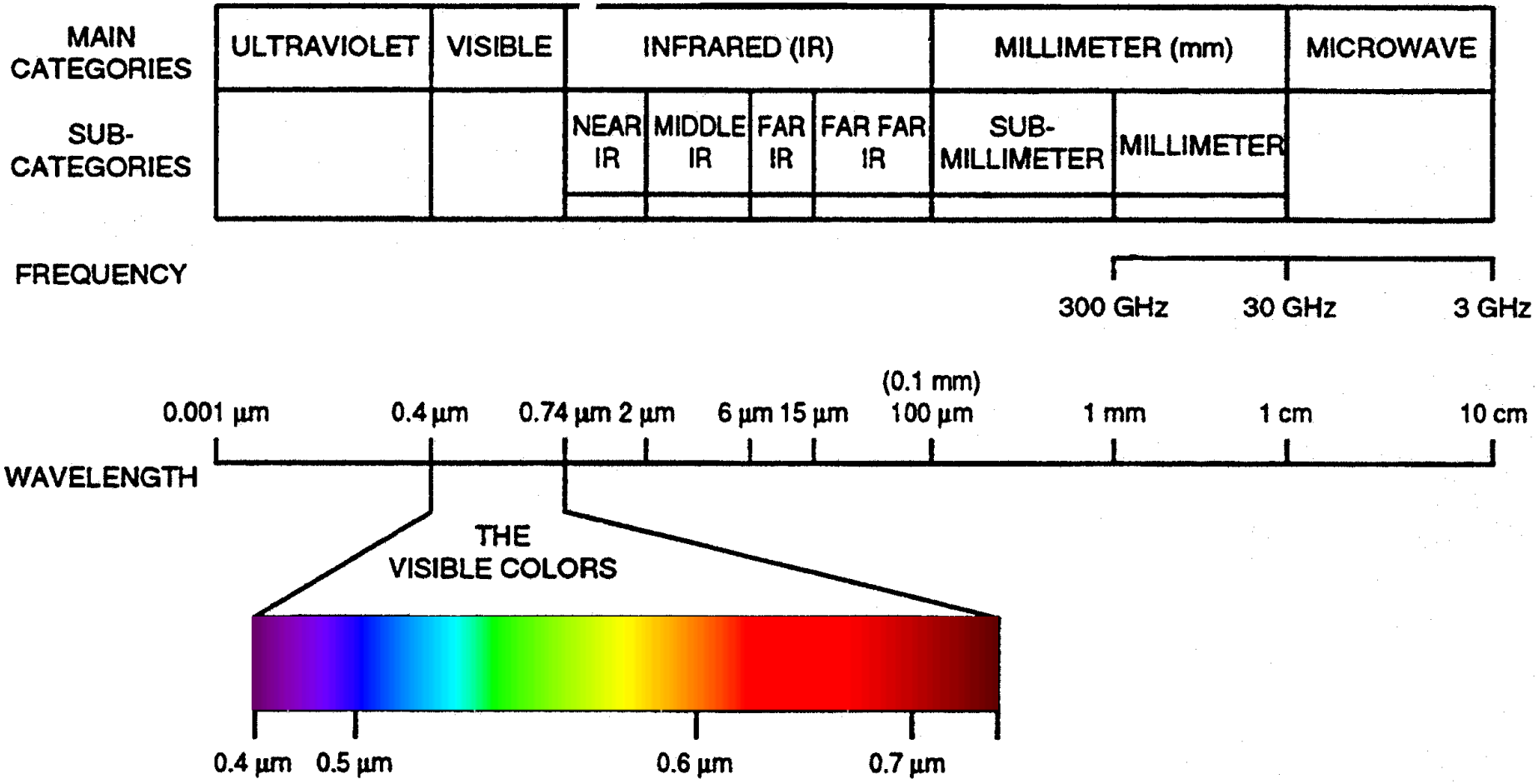
Advantages and Disadvantages of Satellite Imagery

- Disadvantage
  - Interpretation is less straightforward
  - Requires a knowledge of data acquisition and display

Weather Satellite Principles

- Satellite sensing
  - Satellite sensors detect electromagnetic radiation (EMR)
  - EMR travels in wavelengths and is measured in:
    - Micrometers
    - Millimeters
    - Centimeters
  - Computers convert the sensed EMR to a gray shade

Electromagnetic Spectrum



Weather Satellite Principles

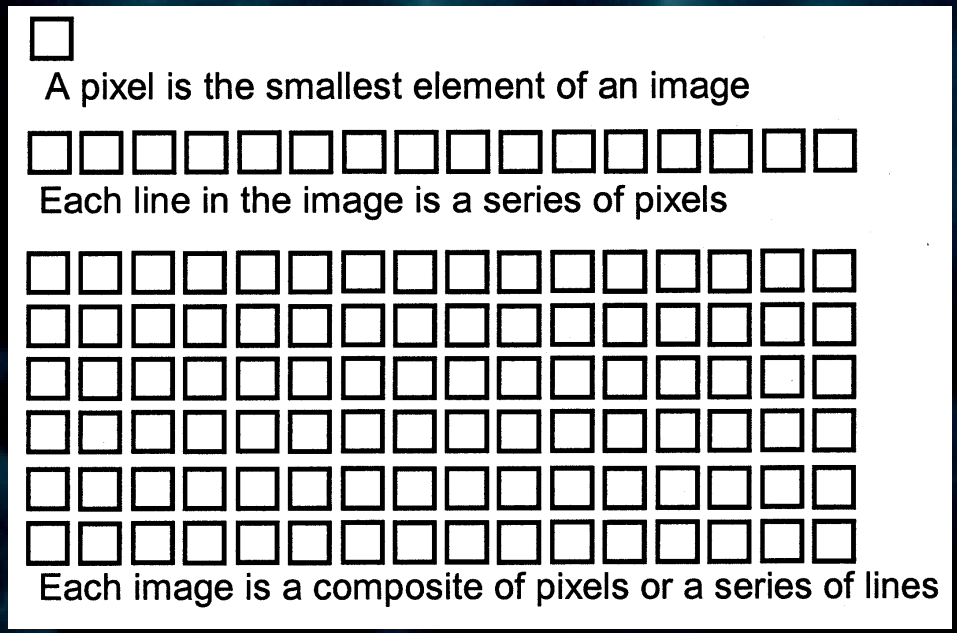
- Transmissivity
- Absorption bands
- Atmospheric windows

Weather Satellite Principles

- Atmospheric windows
  - Channels

Weather Satellite Principles

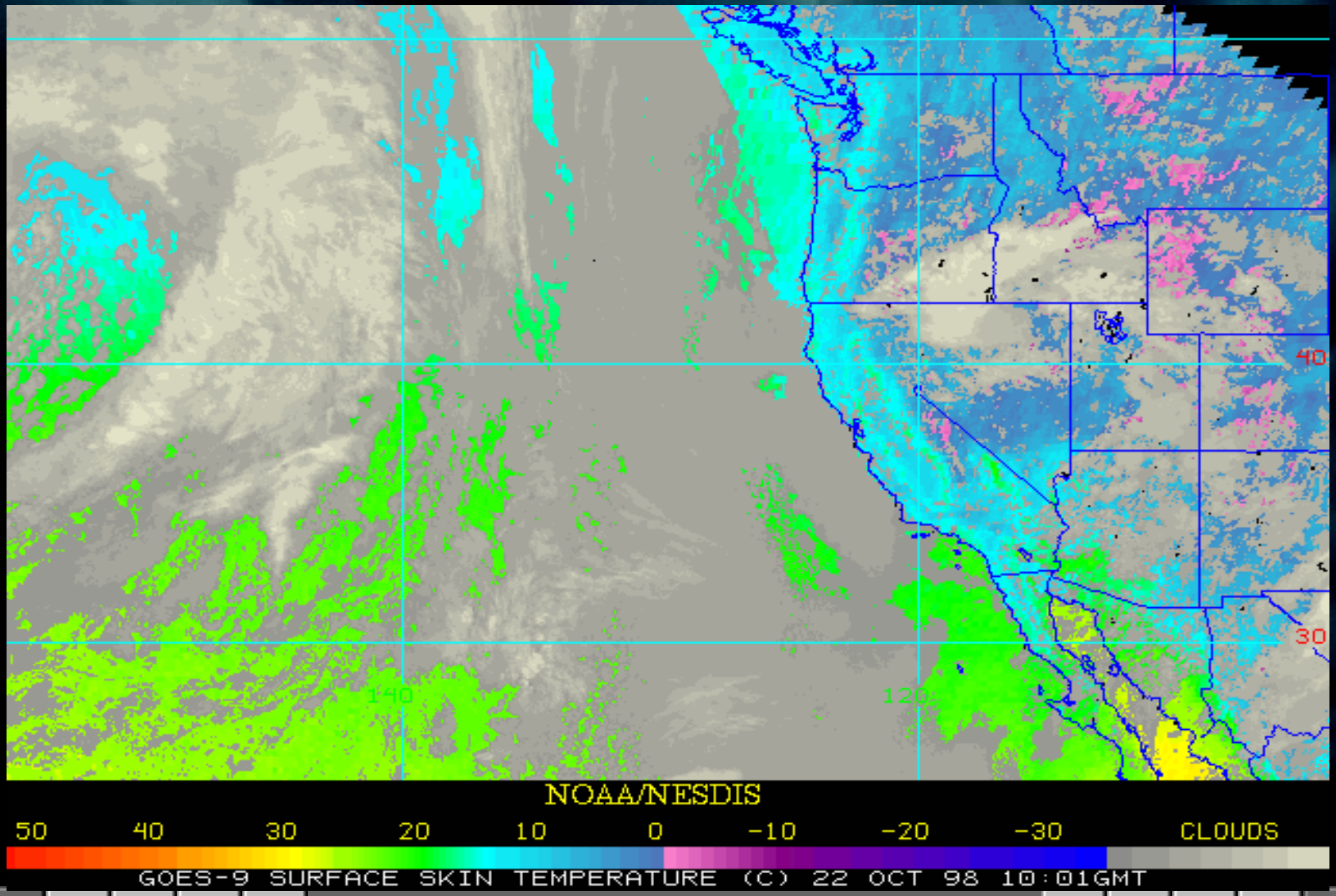
- **Pixels**
  - Tiny squares (pixels) make up the image
  - Each pixel represents a region of the image
  - Satellite senses electromagnetic radiation which is converted into gray shades for the corresponding pixels


A pixel is the smallest element of an image
Each line in the image is a series of pixels
Each image is a composite of pixels or a series of lines

Weather Satellite Principles

- Gray shades
  - 256 gray shades available
  - Gray shades are assigned to each pixel representing a temperature
  - The human eye distinguishes 15-20 gray shades
  - Computer enhancements allow the user to distinguish images more easily

Enhancement Curve

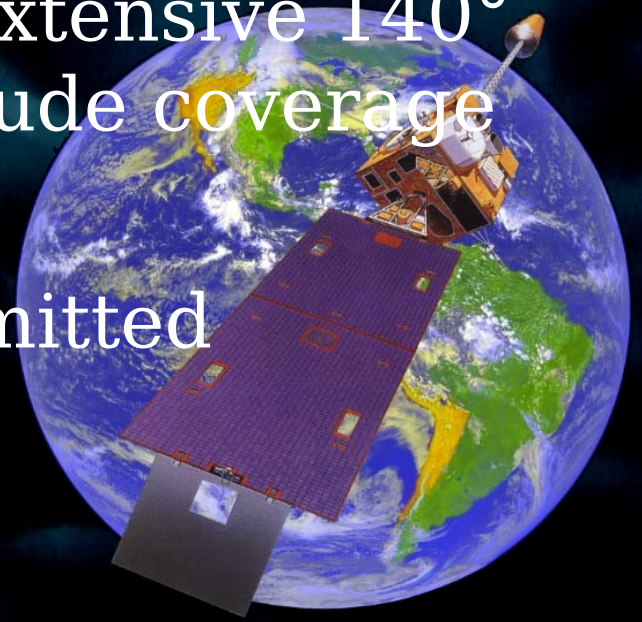


Review

- Advantages/ disadvantages
- Satellite principles
  - Satellite sensing
    - Transmissivity
    - Absorption bands
    - Atmospheric windows
    - Pixels
  - Gray scale

Weather Satellite Systems

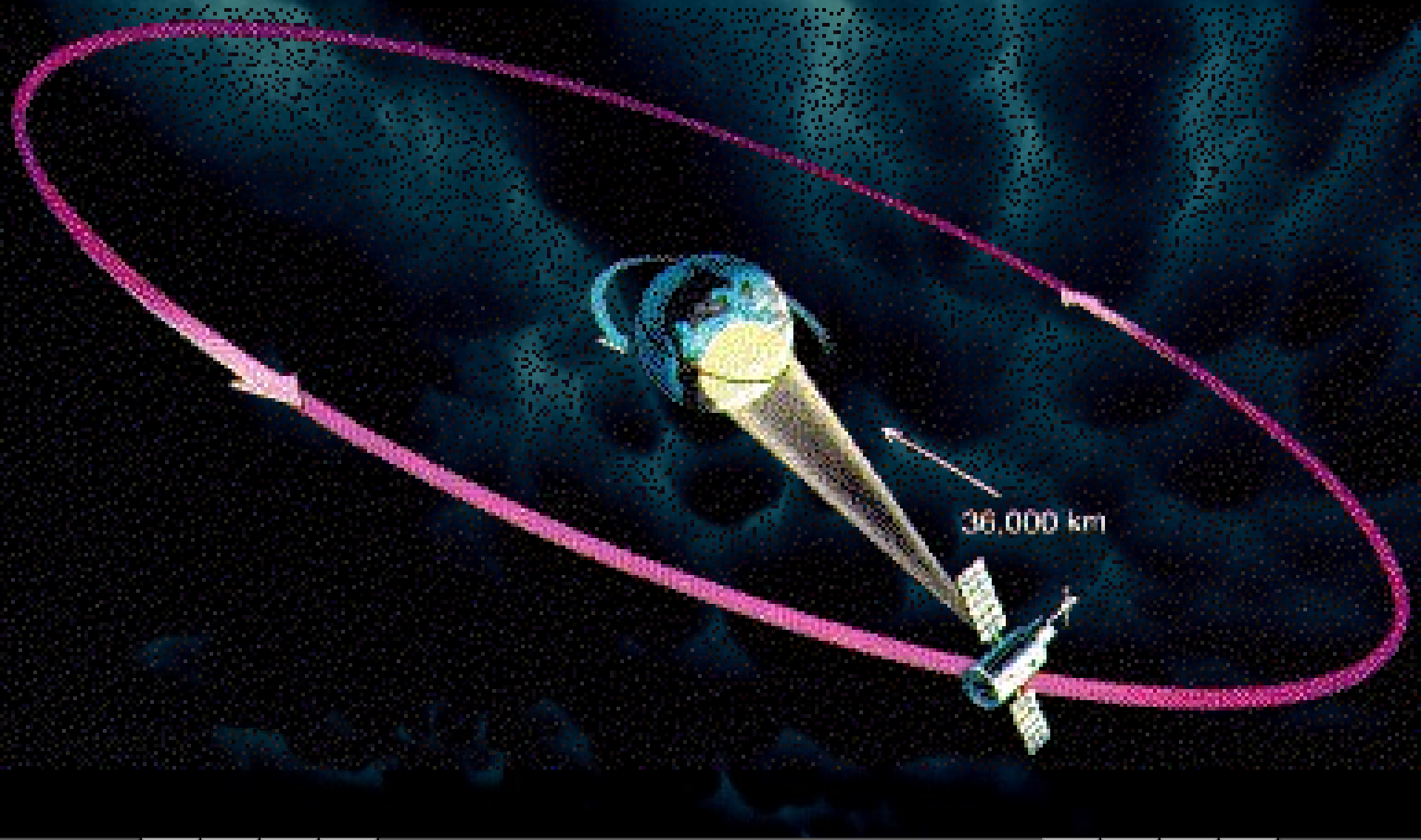
- Geostationary satellites
  - Remain in orbit over equator in fixed spot
  - High altitude permits extensive 140° latitude by 140° longitude coverage
  - 24 hour coverage
  - Images normally transmitted Every 30 minutes



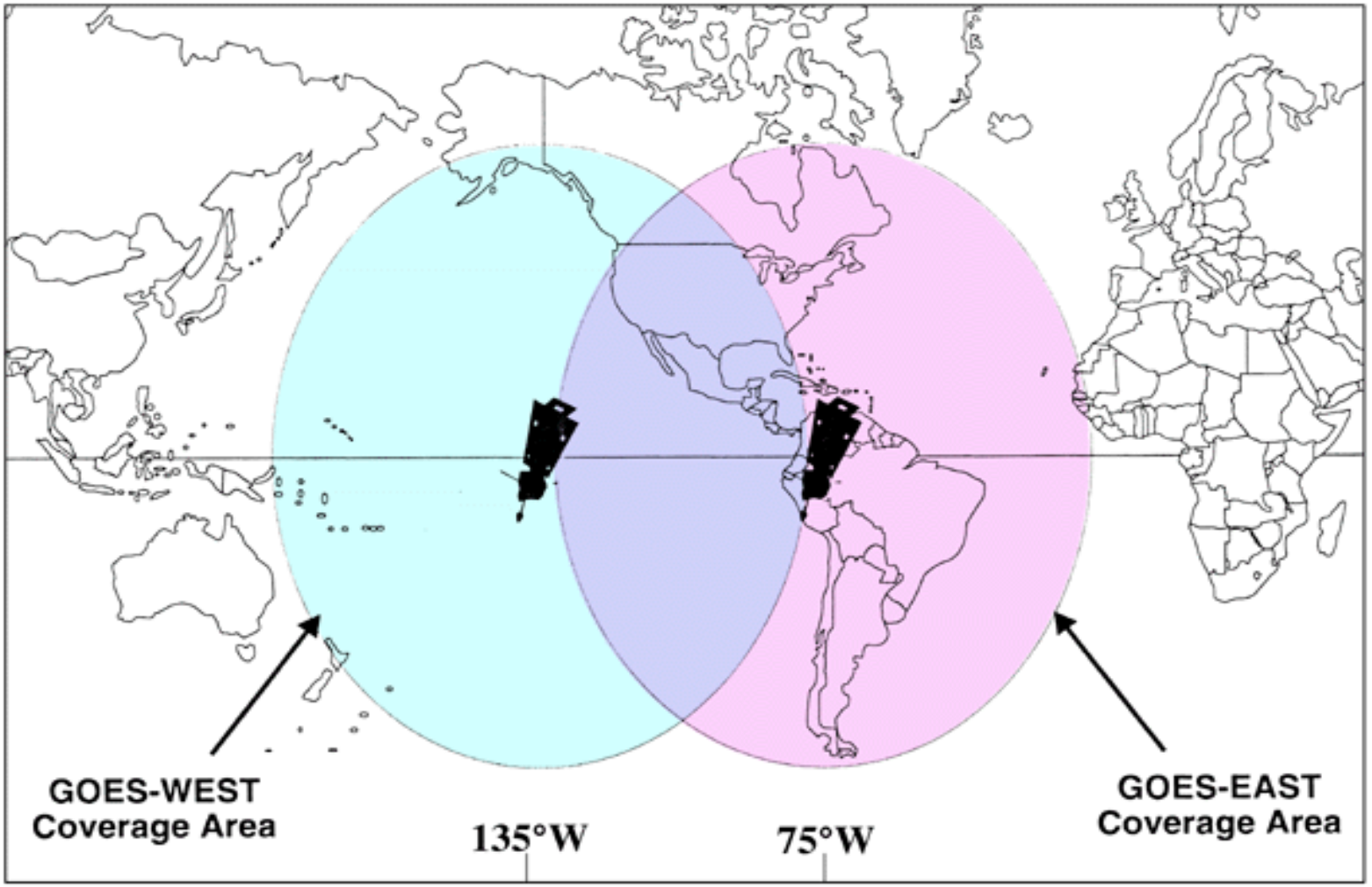
Weather Satellite Systems

- 1966 Applications Technology Satellite (ATS series)
  - In 1974 the Synchronous Meteorological Satellite (SMS 1 & 2) series was launched
  - In 1975, GOES series (1, 2 & 3) was launched

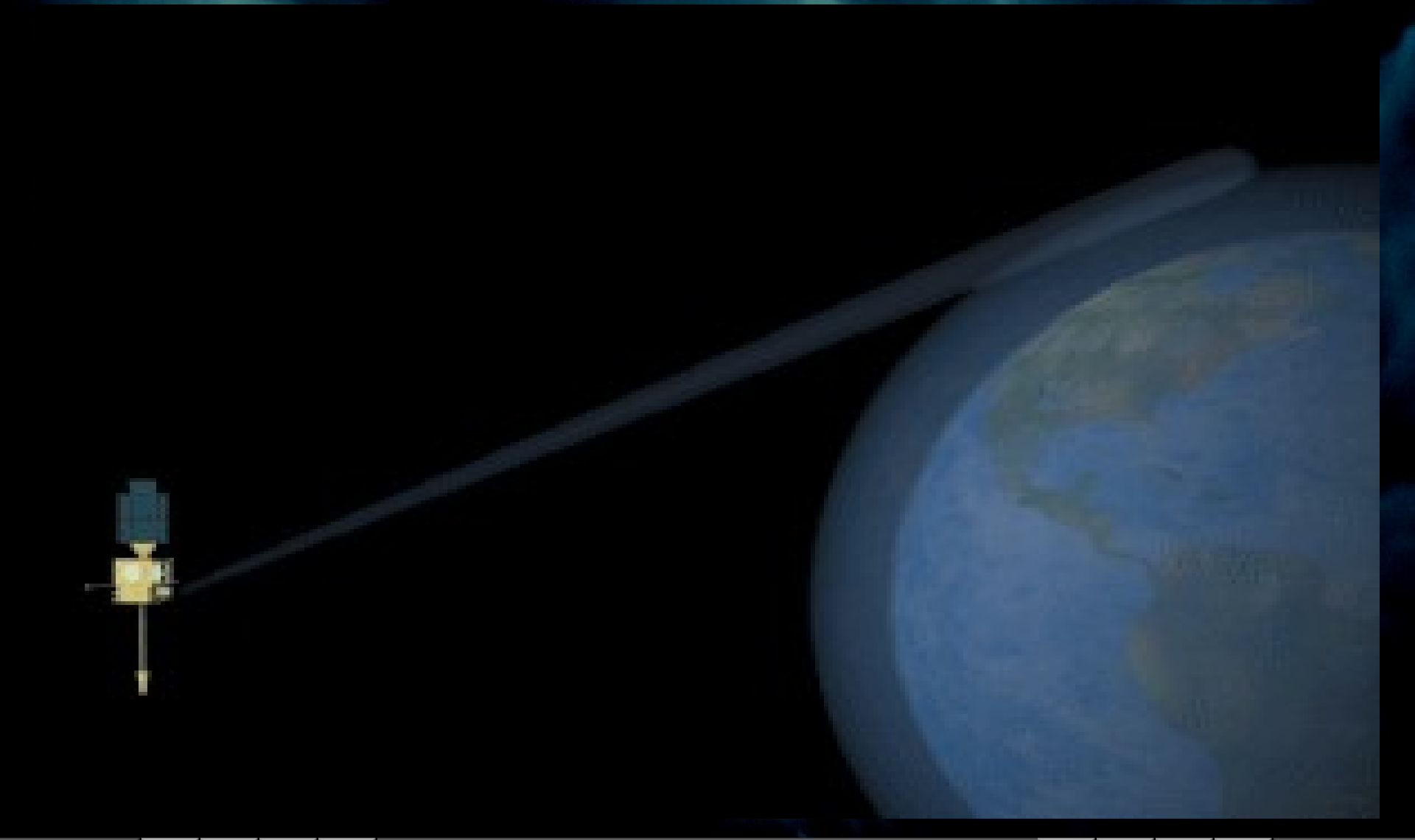
GOES Orbit



GOES Coverage

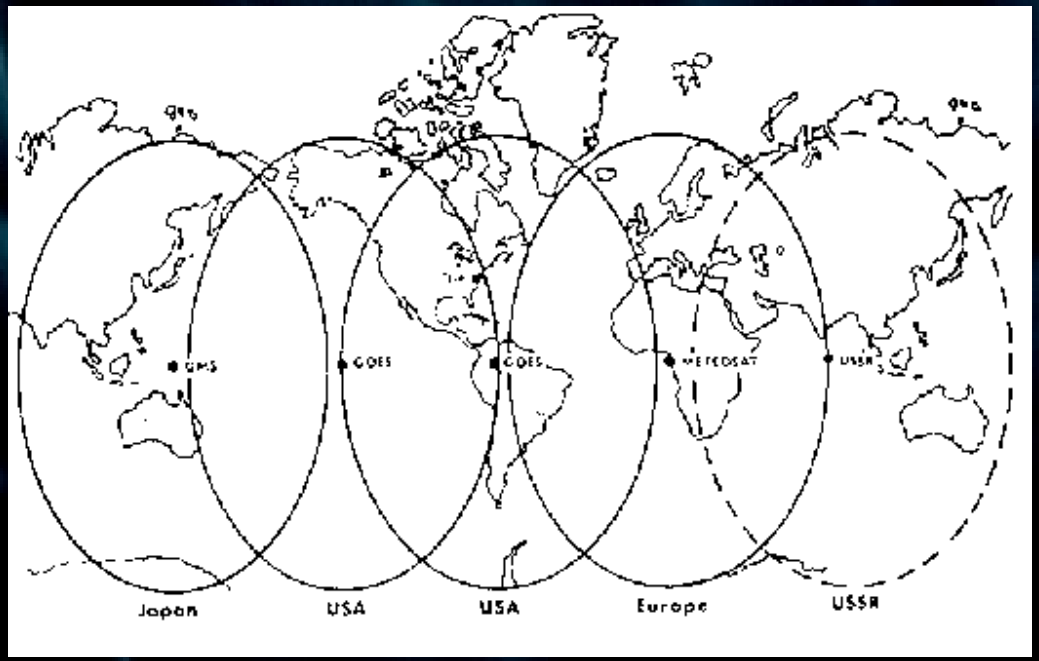


GOES Satellite

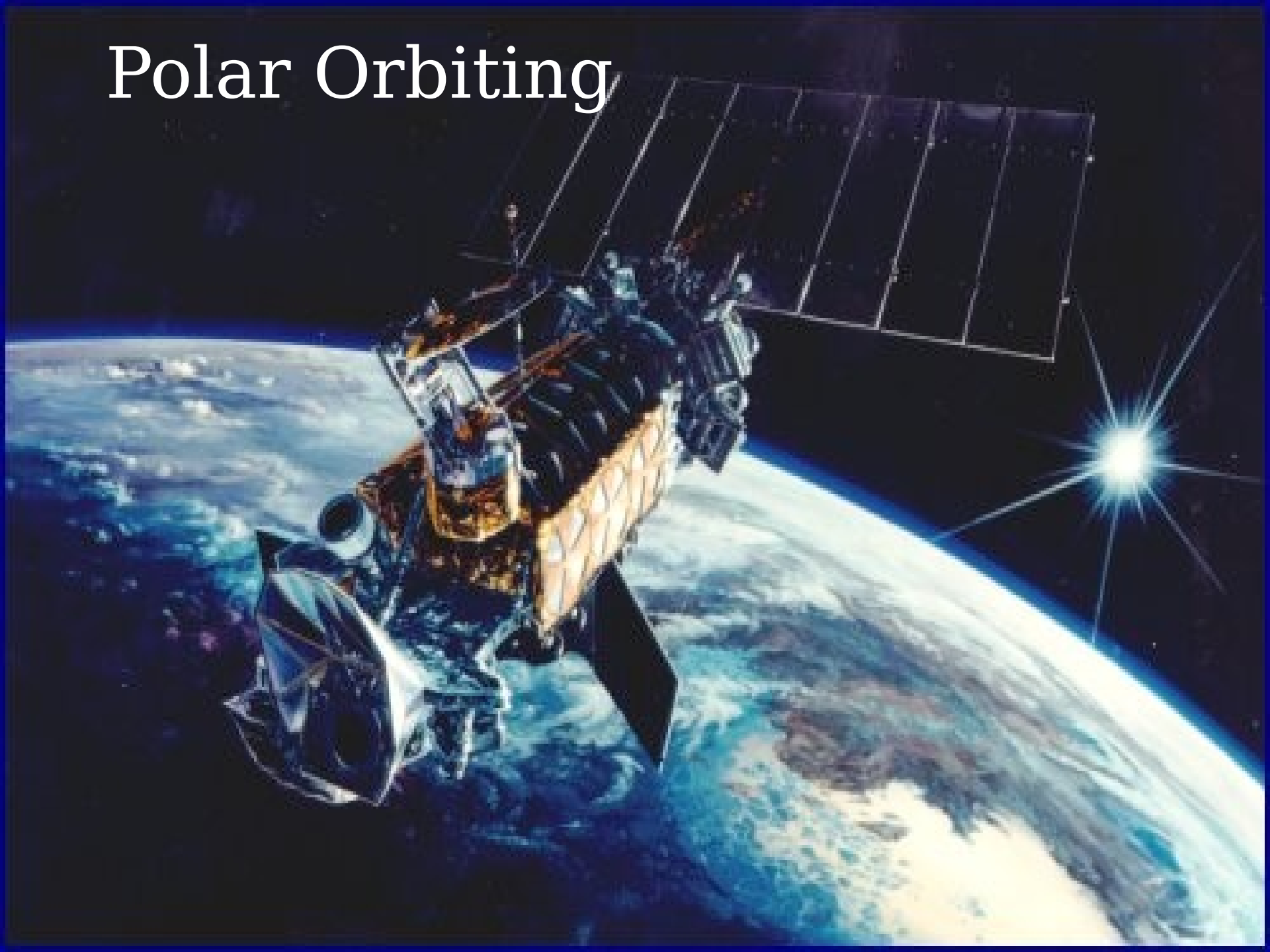


Satellite Types
Geostationary Systems

- Operational geostationary satellites
- Main Sources
  - United States
    - GOES East
    - GOES West
  - Japan (GMS)
  - Europe (METEOSAT)
  - India (INSAT)
  - Russia (GOMS or ELECTRO)



Polar Orbiting



Satellite Types Polar Orbiting

- Polar Orbiting Satellites
  - Parallel Earth's meridian lines
  - Circles at a lower attitude
  - The first polar orbiting satellite was TIROS 1
  - The path width varies with latitude, and is about 27° wide at the equator

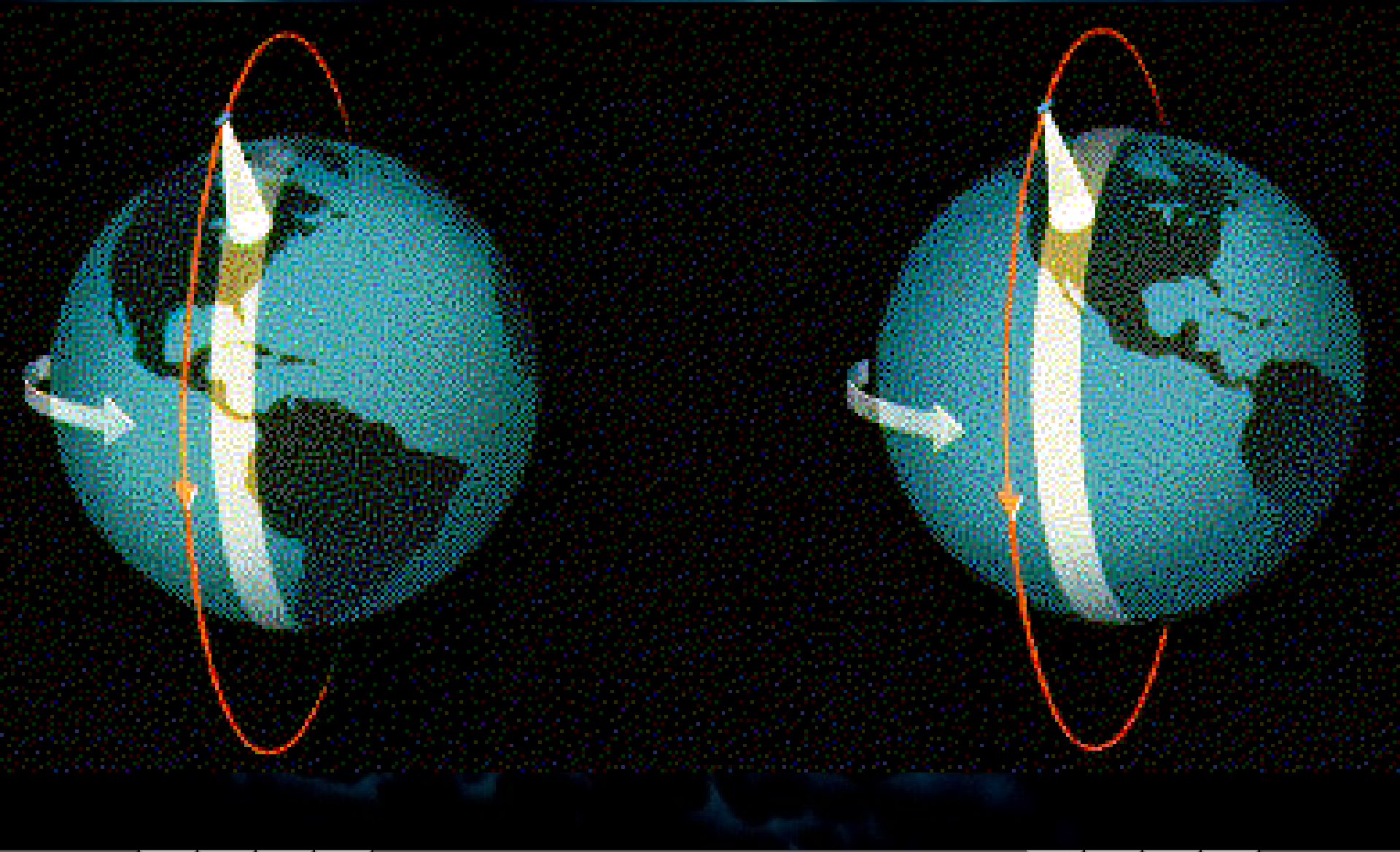
Satellite Types
Polar Orbiting

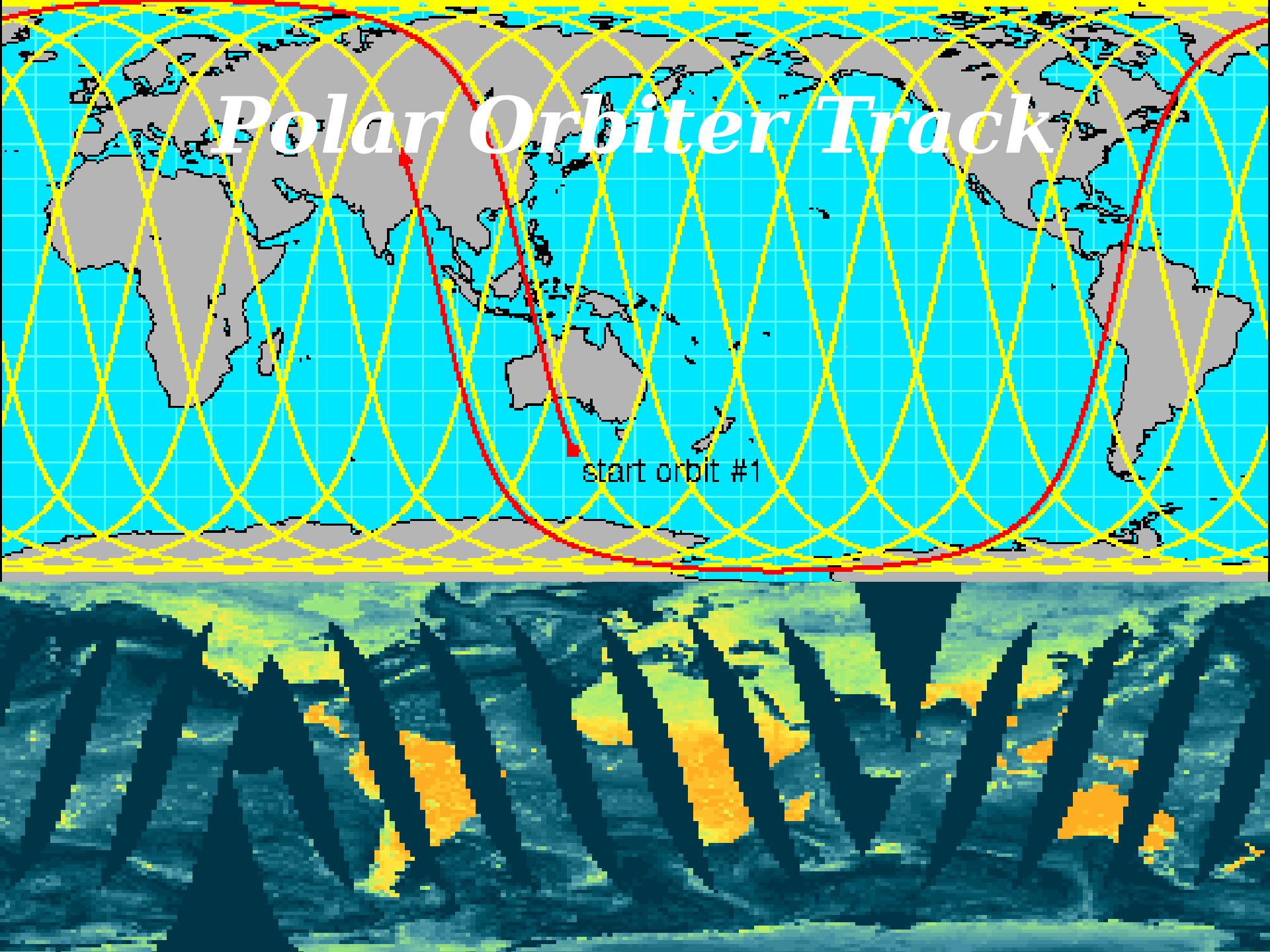
- Current operational polar orbiting satellites
  - Defense Meteorological Satellite Program (DMSP)
  - National Oceanic Atmospheric Administration (NOAA)
  - ERS 1/2 - European Space Agency
  - QUIKSCAT - NASA
  - TRMM - Tropical Rainfall Measuring Mission. Joint mission between NASA and NASDA (National Space Development Agency of Japan)
- The United States maintains at least two operational NOAA satellites at all times

Satellite Types
Polar Orbiting

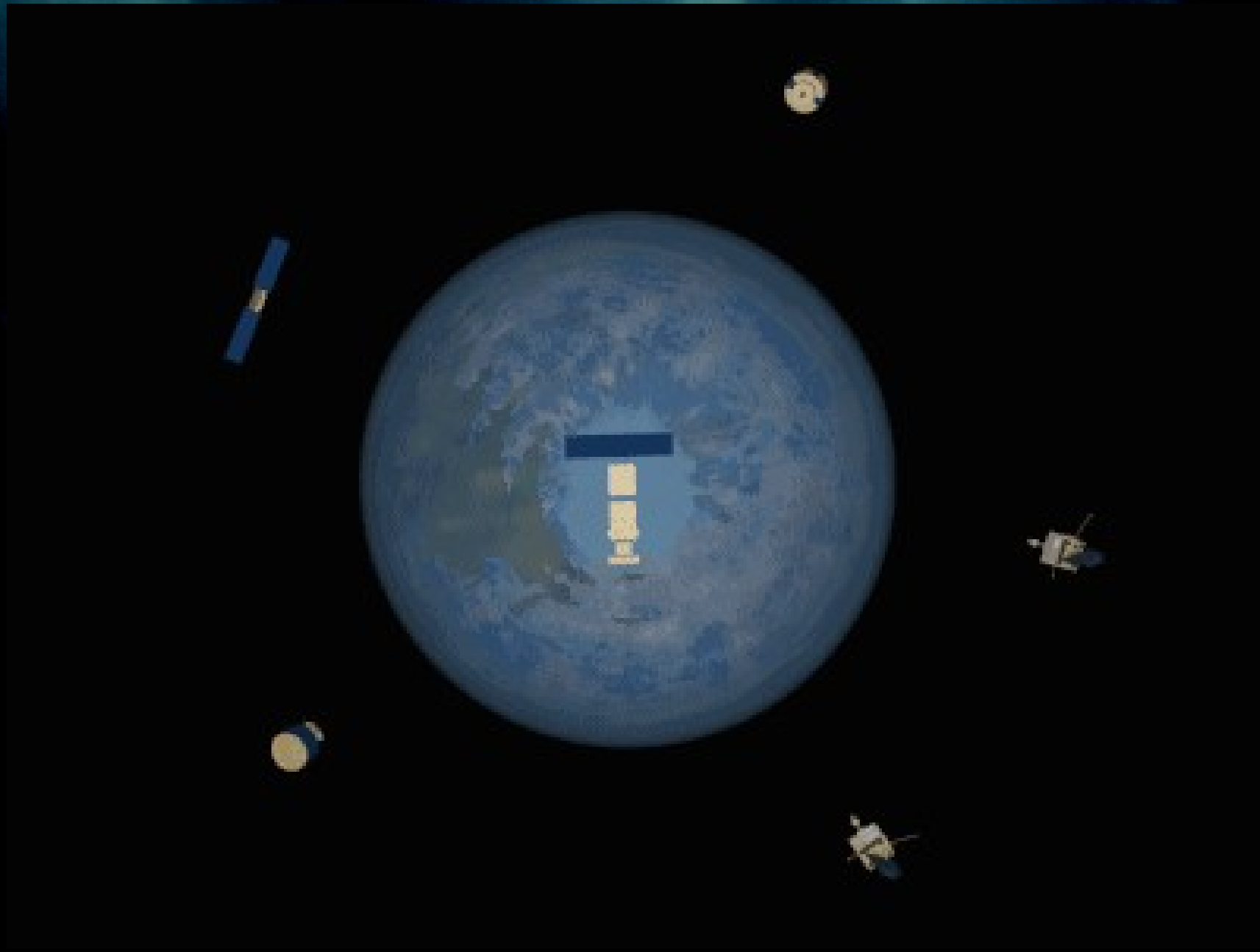
- Advantages
  - High resolution images available
  - Polar region coverage
  - These satellites provide global cover age every 12 hours

Polar Orbiting Satellite




Polar Orbiter Track
start orbit #1

Polar Orbiter Animation



Resolution

- Finer (greater or higher) resolution allows smaller individual elements to be seen
  - If objects are smaller than resolution of sensor
    - Individual elements will not be seen
    - Gray shades averaged
  - If objects are larger than resolution of sensor object will be displayed normally
- Lower resolution images do not allow small elements to be seen resulting in less detailed image

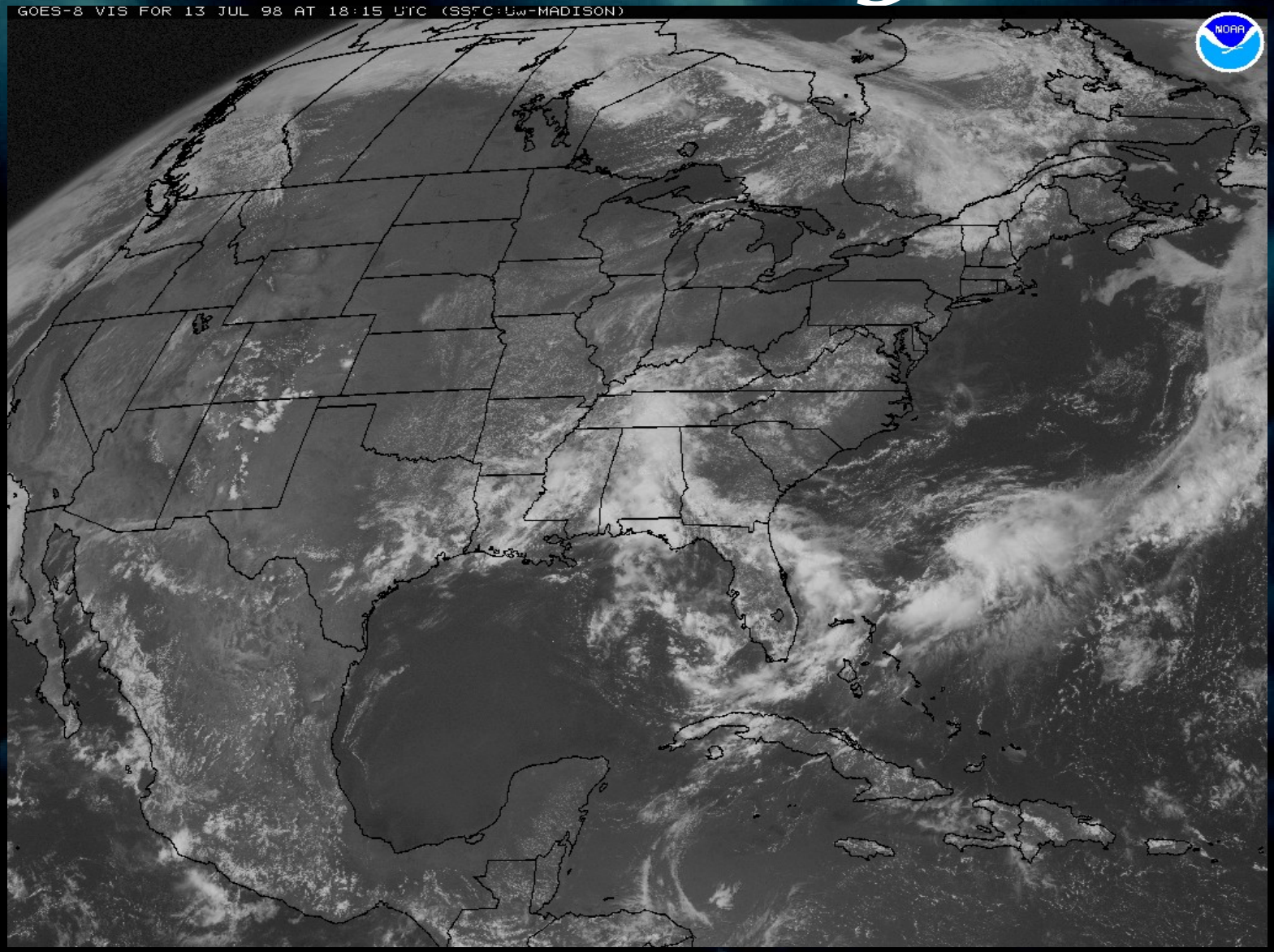
Visible Satellite Imagery

- Visible imagery (VIS)
  - Uses atmospheric window (visible light portion)
  - Measures reflected solar radiation of the same wavelengths detected by the human eye (.4 - .7μm)
  - Visual imagery looks like a black and white picture of the earth from outer space

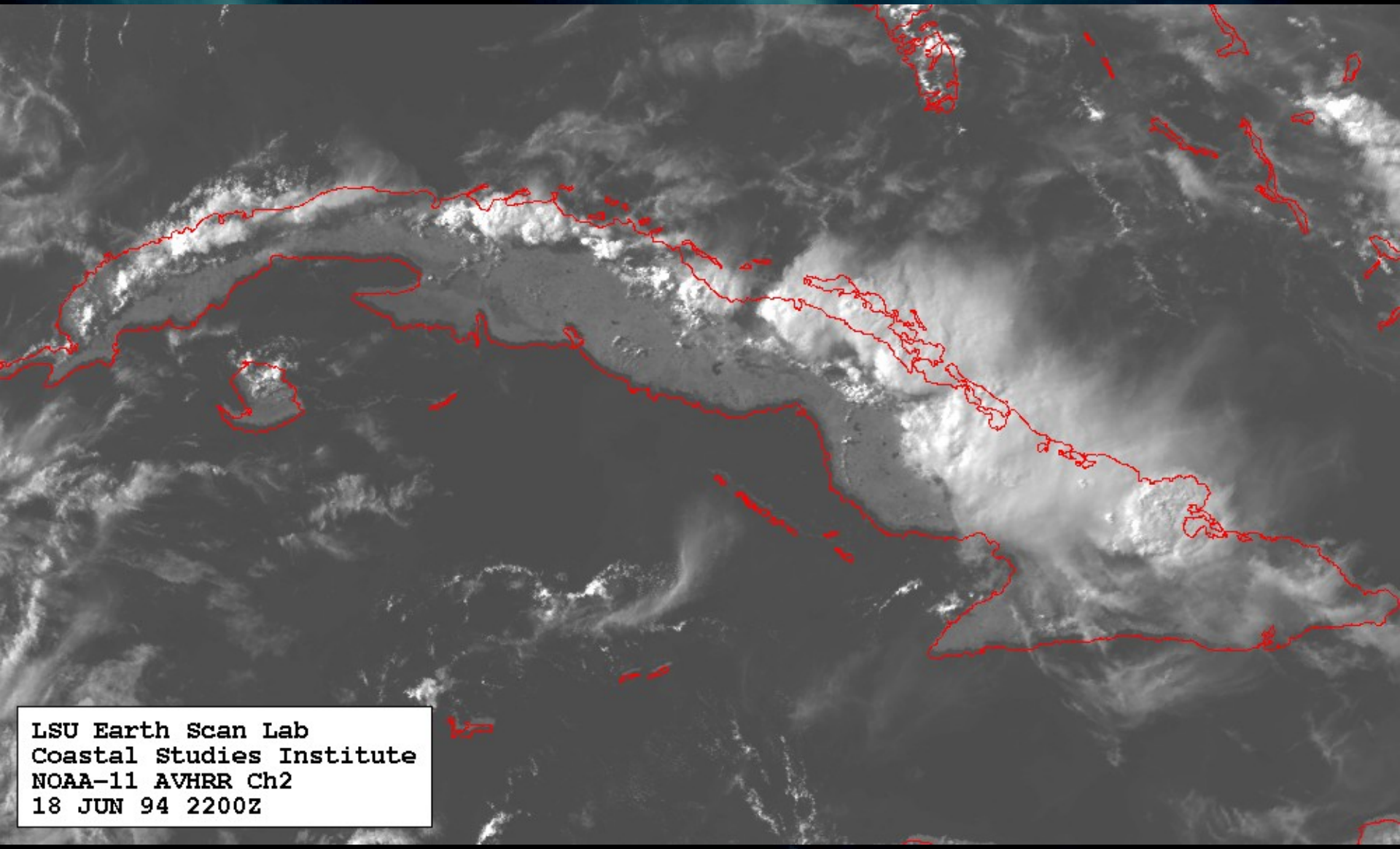
Visible Satellite Imagery

- Factors affecting brightness
  - Illumination is dependent upon four factors
    - Time of day
    - Time of year
    - Latitude
    - Cloud height

Visible Image



Thunderstorms in Cuba



Visible Satellite Imagery

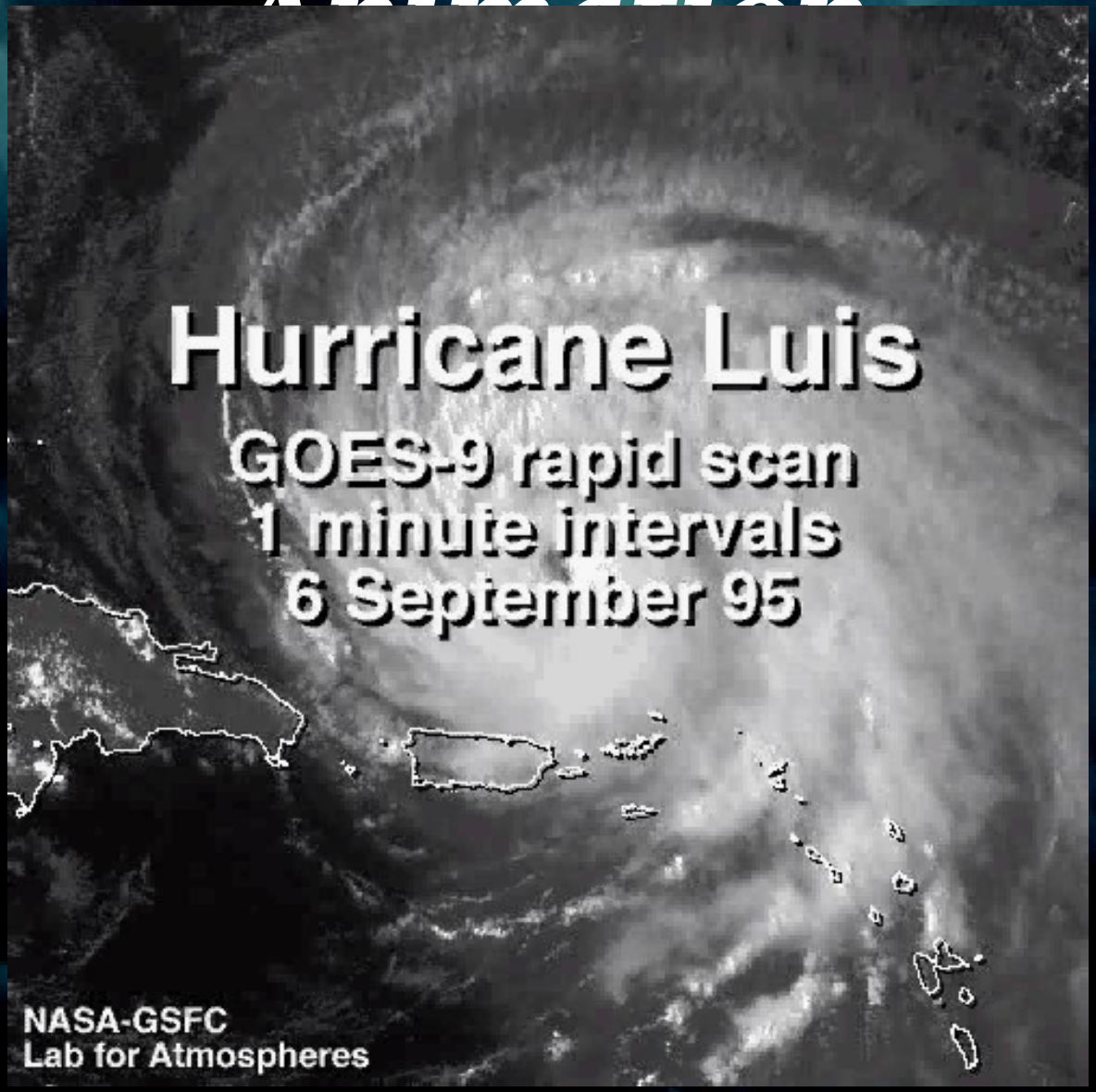
- Factors affecting the brightness (of cloud and non-cloud features)
  - Albedo – reflectivity
    - Objects with higher albedo reflect more
    - Water droplets reflect five times more than ice crystals
      - Clouds composed of water droplets appear brighter
      - Visible imagery is more suitable for low clouds
      - High clouds do not show up on visible imagery as well
  - Thicker clouds reflect more sunlight, appearing brighter

Reflectivity (in Percent) of Various Surfaces in Visual Imagery.

Surface	%
Large thunderstorm	92
Fresh new snow	88
Thick cirrostratus	74
Thick stratocumulus	68
White sands, NM	60
Snow, 3-7 days old	59

Surface	%
Thin stratus	42
Thin cirrostratus	32
Sand, no foliage	27
Sand & brushwood	17
Coniferous forest	12
Water surfaces	9

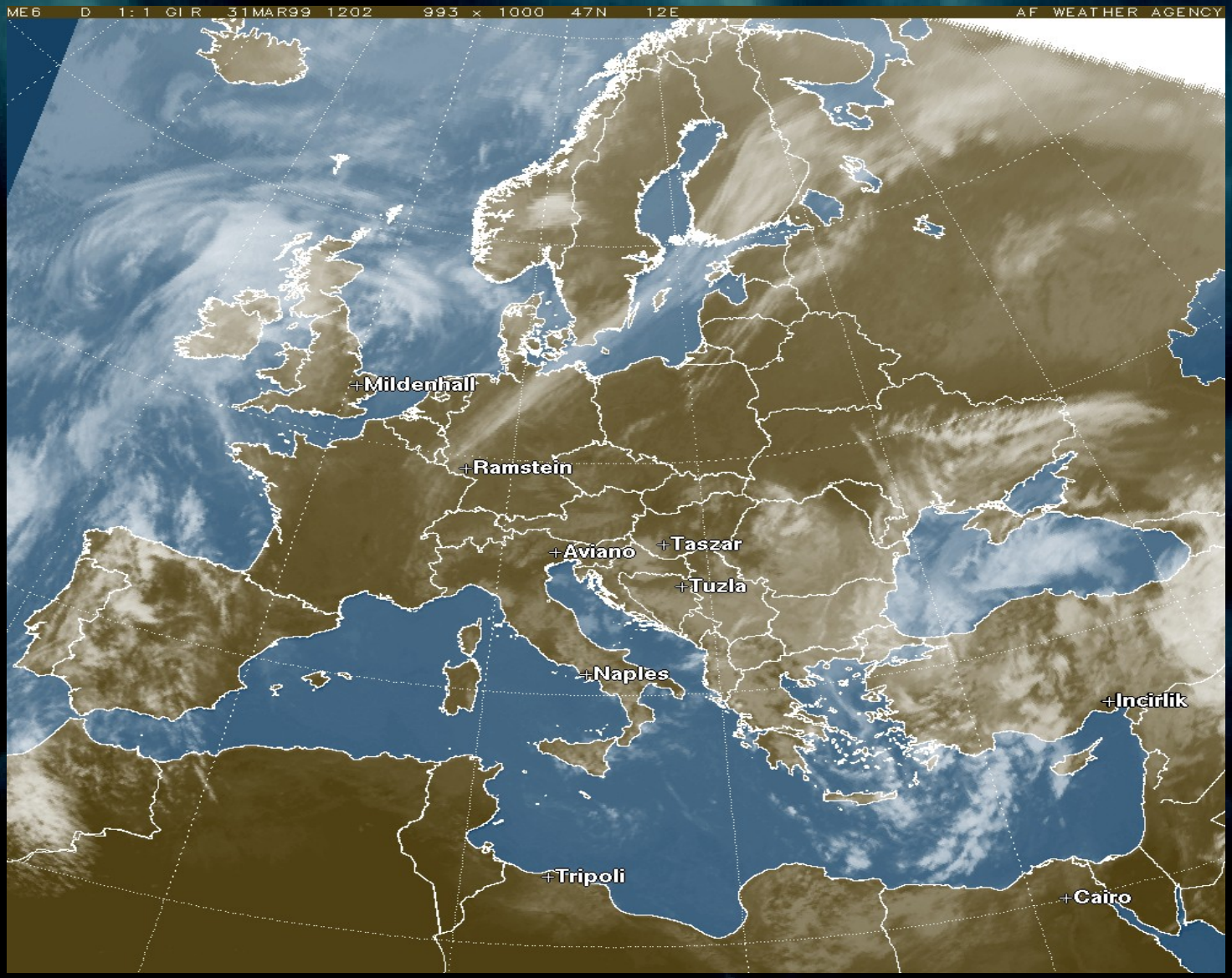
Sunset Visual Animation



Satellite Imagery

- Infrared imagery
  - Available 24 hours a day
  - .7 - 12.8 μm range
  - Temperatures of the object used
    - Warm/hot objects emit radiation at shorter wavelengths
    - Cool/cold objects emit radiation at longer wavelengths

Infrared Image



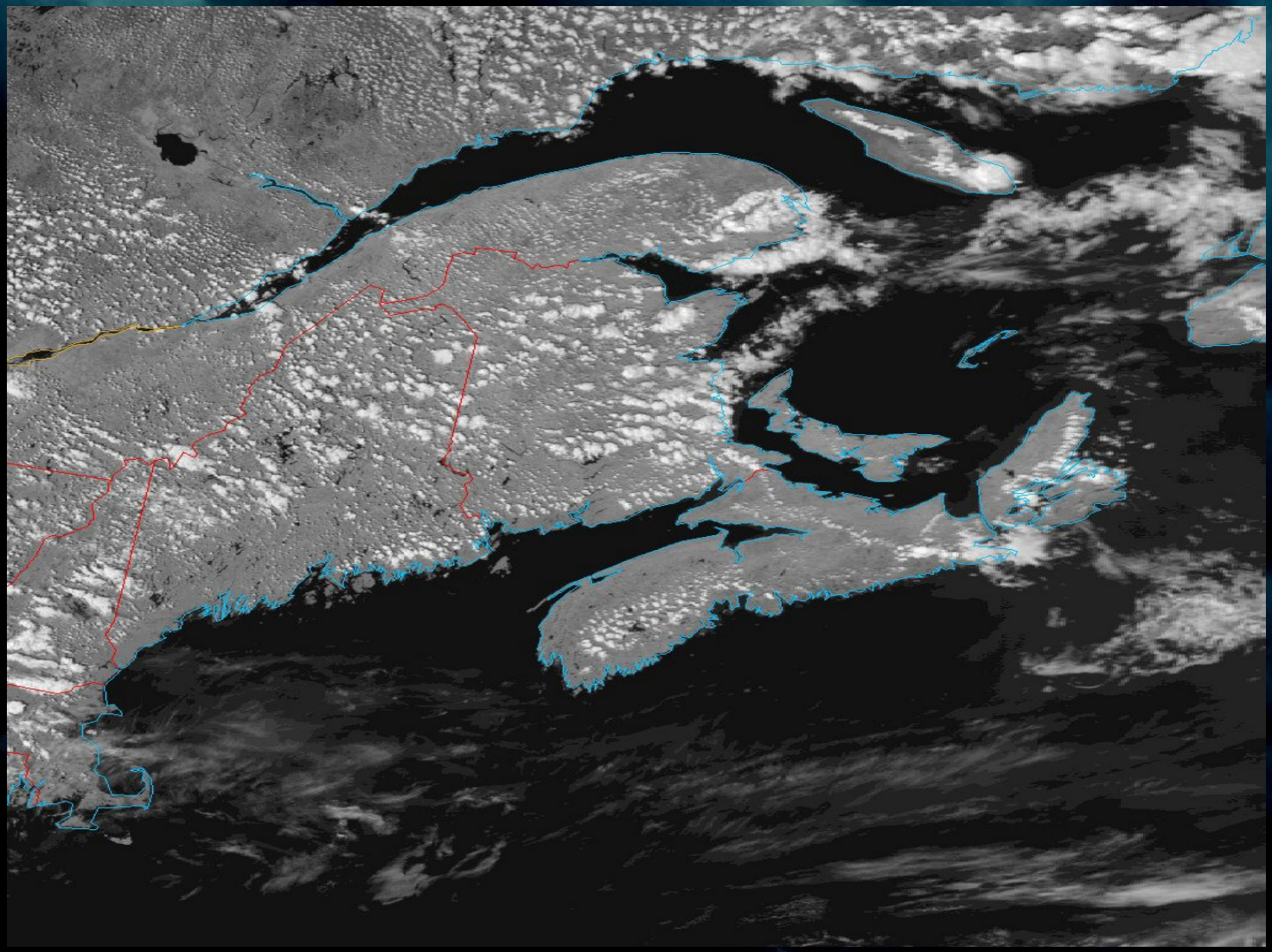
Near Infrared Imagery

- Measures both reflected solar radiation and emitted radiation
- Factors that affect brightness are the same as visible images
  - Illumination
  - Albedo

Near Infrared Imagery

- Objects that reflect best include
  - Vegetation
  - Lithometeors (haze and dust)
- Availability
  - 24 hours a day
  - Works best during day when picking up reflected sunlight

Northeastern America



Satellite Imagery

- Infrared imagery
  - The gray shade assigned to each pixel corresponds to the temperature of the object
    - Cold temperatures normally appear lighter
    - Warm temperatures normally appear darker

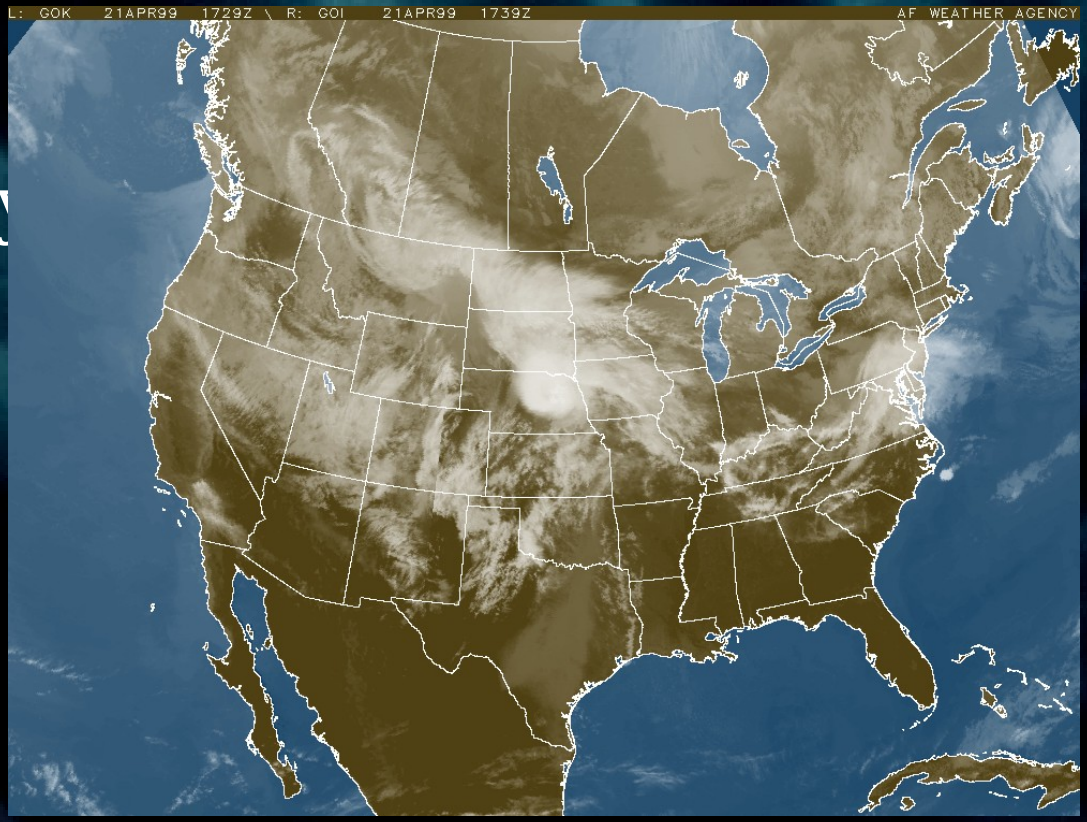
Urban heat islands
5 July 1999 2045 UTC
4-micron infrared
GOES-8

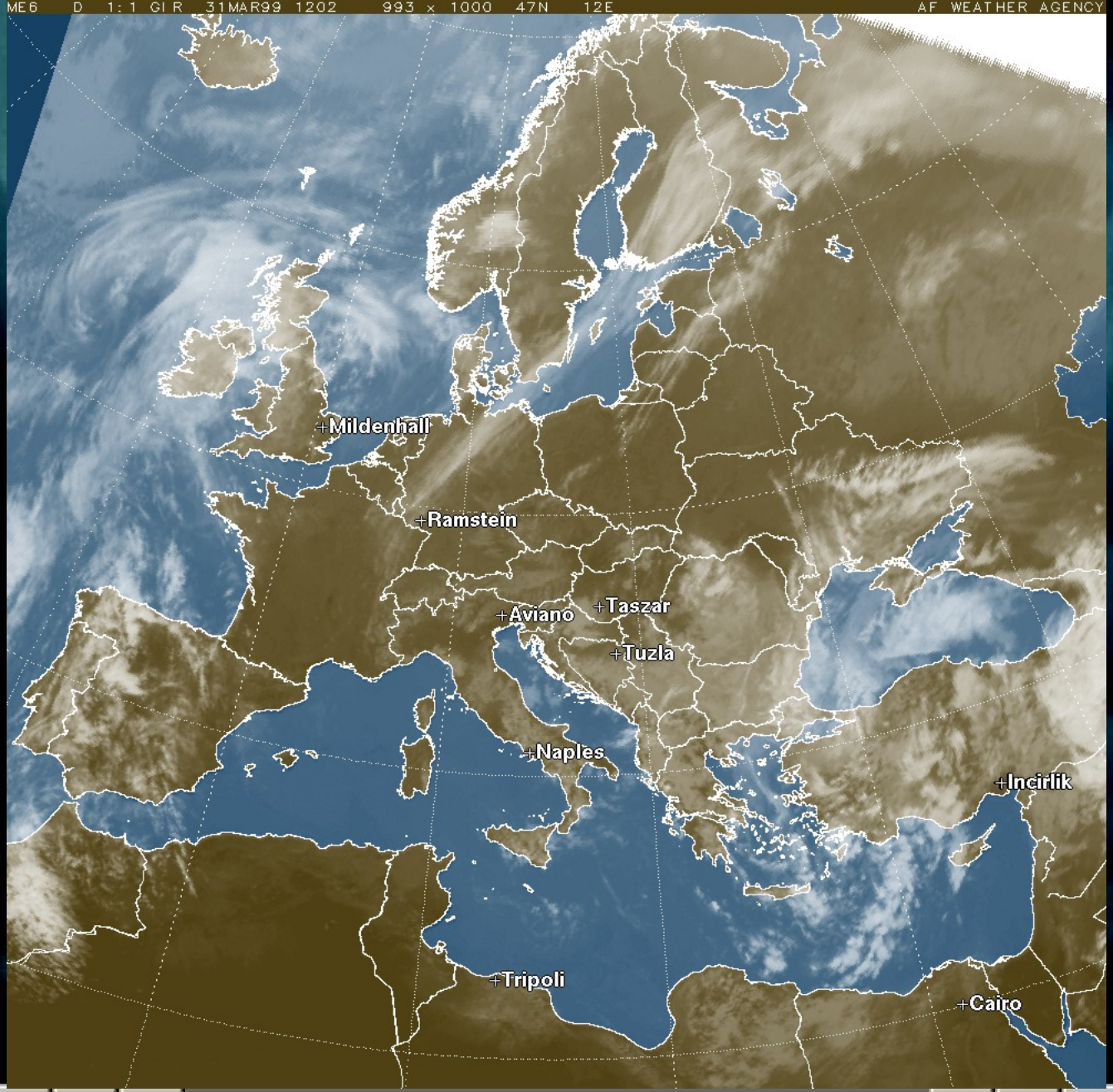
Far Infrared Imagery

- Measures emitted radiation in much longer wavelengths
  - Amount of long wave radiation sensed is dependent upon temperature of object
    - Warm objects emit shorter wavelengths
    - Cool objects emit longer wavelengths
  - Far infrared imagery does well identifying high clouds and upper-level flow

Far Infrared Imagery

- Availability
  - 24 hours a day
  - Does not rely on sunlight




ME6 D 1:1 GIR 31MAR99 1202 993 x 1000 47N 12E
AF WEATHER AGENCY
Mildenhall
Ramstein
Aviano
Taszar
Tuzla
Naples
Incirlik
Tripoli
Cairo

Satellite Imagery

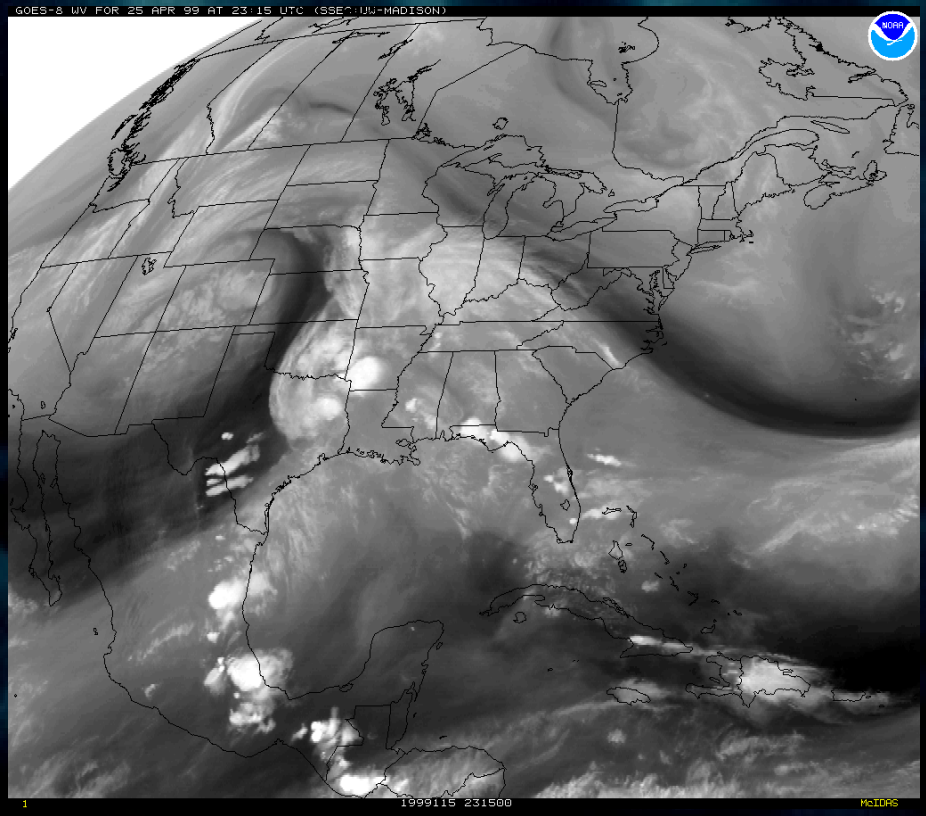
- Water vapor imagery (WV) or the moisture channel.
  - Satellite sensors zero in on the energy absorbed by the atmosphere.
  - Measures radiation emitted from 5.7 to 7.4 μm. Generally, the 6.7 μm channel is used.

Satellite Imagery
Water Vapor

- WV measures emitted radiation at 6.7 micrometers which is the exact wavelength water vapor is absorbed well
  - Greatest absorption is between 610 mb and 240 mb (approximately 13,500-35,000 feet)
  - Water vapor imagery detects middle and upper-level moisture moisture
  - Low-level moisture is nearly invisible

Water Vapor
Temperature Considerations

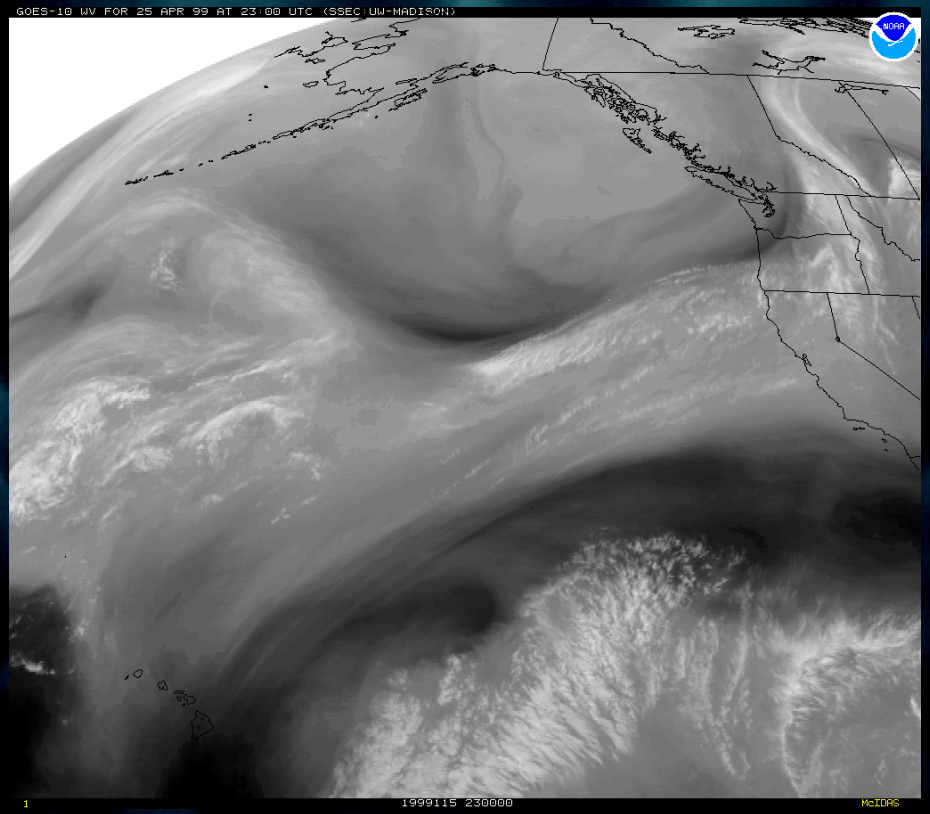
- Difference in brightness (gray shades) depends on temperature and water vapor content



Water Vapor
Temperature Considerations

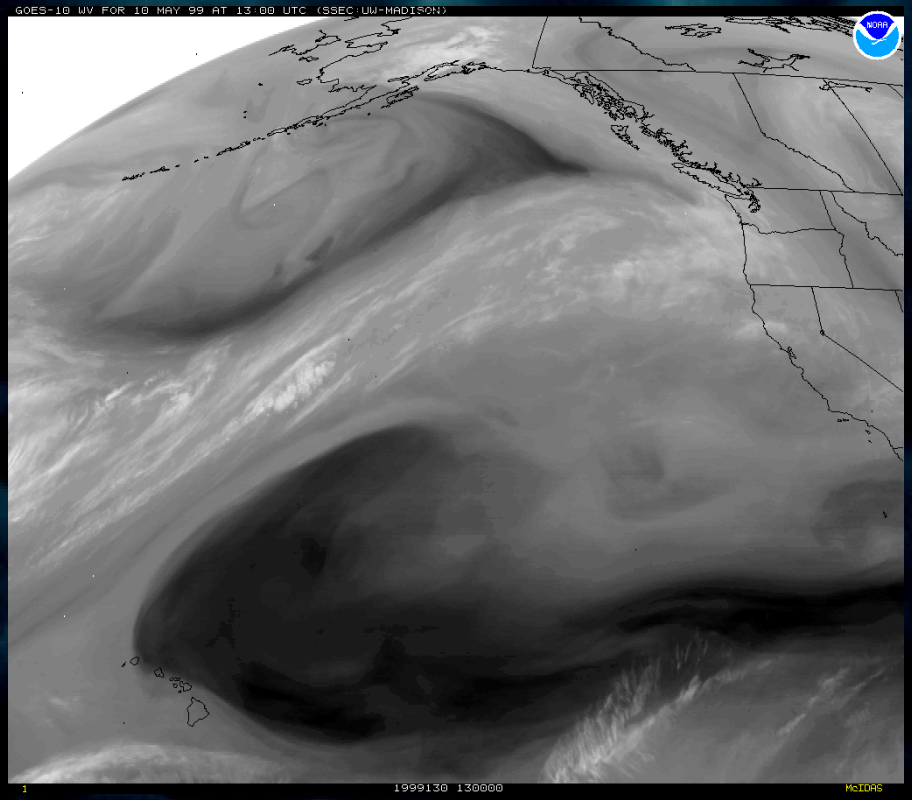
Warm areas

- Low level warm areas that are moist in upper level
  - Absorb most of the emitted radiation
  - Little radiation reaches the satellite and area appears cool light gray



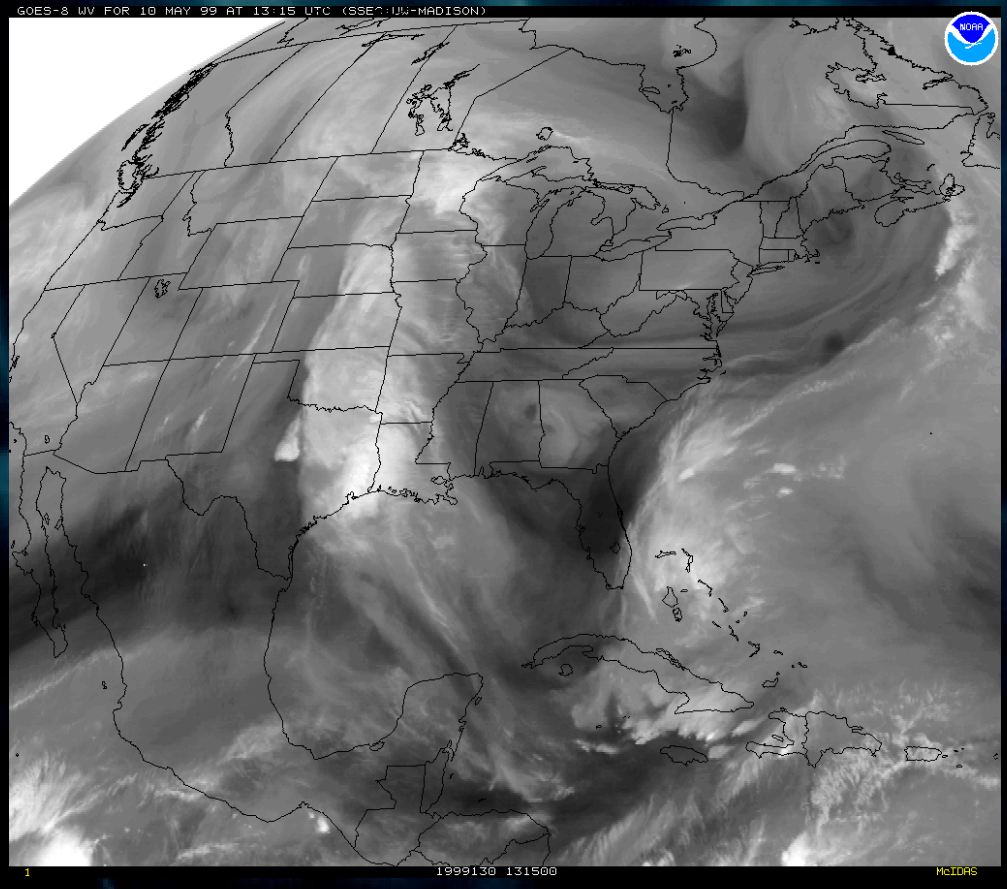
Water Vapor
Temperature Considerations

- Warm low level areas that are dry in the upper levels
  - Little absorption of radiation takes place
  - Significant radiation reaches the satellite and the area appears warm (dark gray)



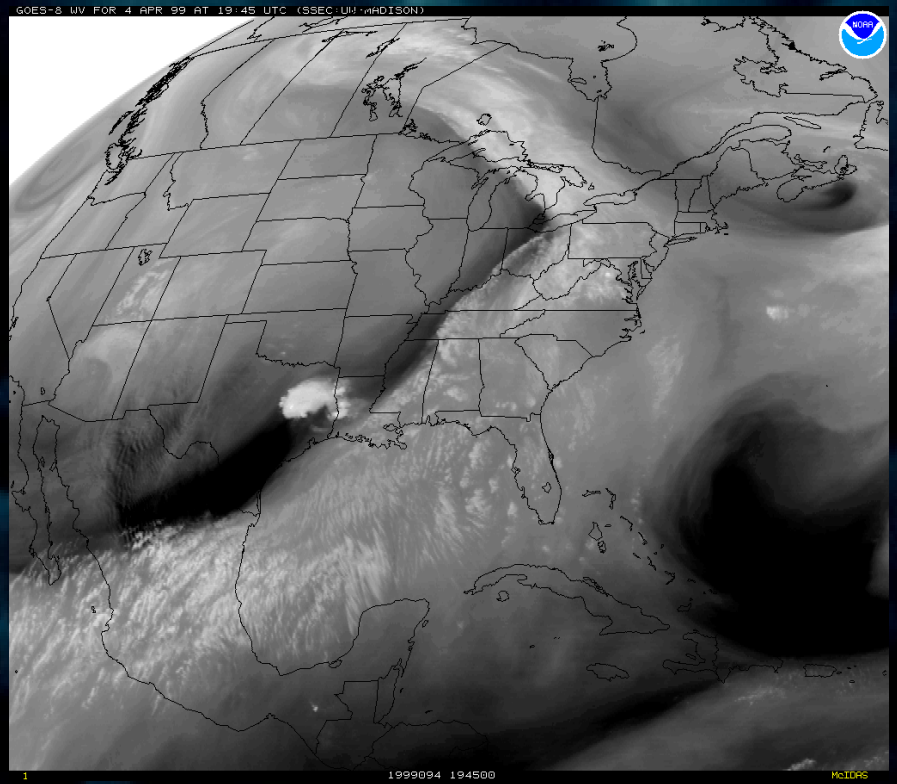
Water Vapor
Temperature Considerations

- Cool areas
  - Emit little radiation and only small amounts reach the satellite
  - Moisture content is irrelevant and area appears cool (light gray)



Water Vapor

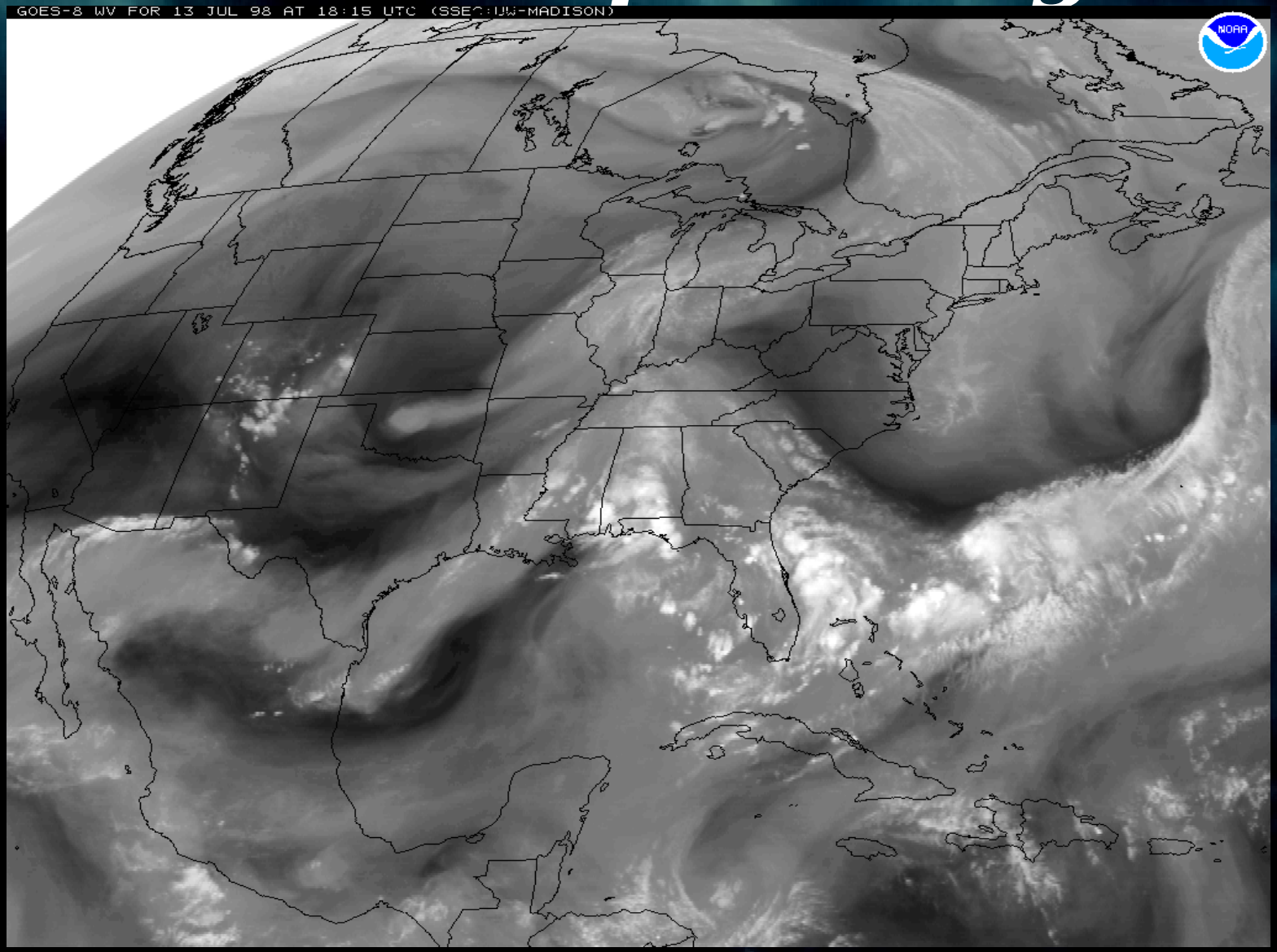
- Typical uses
  - Moisture analysis
    - Moist areas indicate upward vertical motion
    - Dry areas indicate downward vertical motion
  - Jet stream analysis



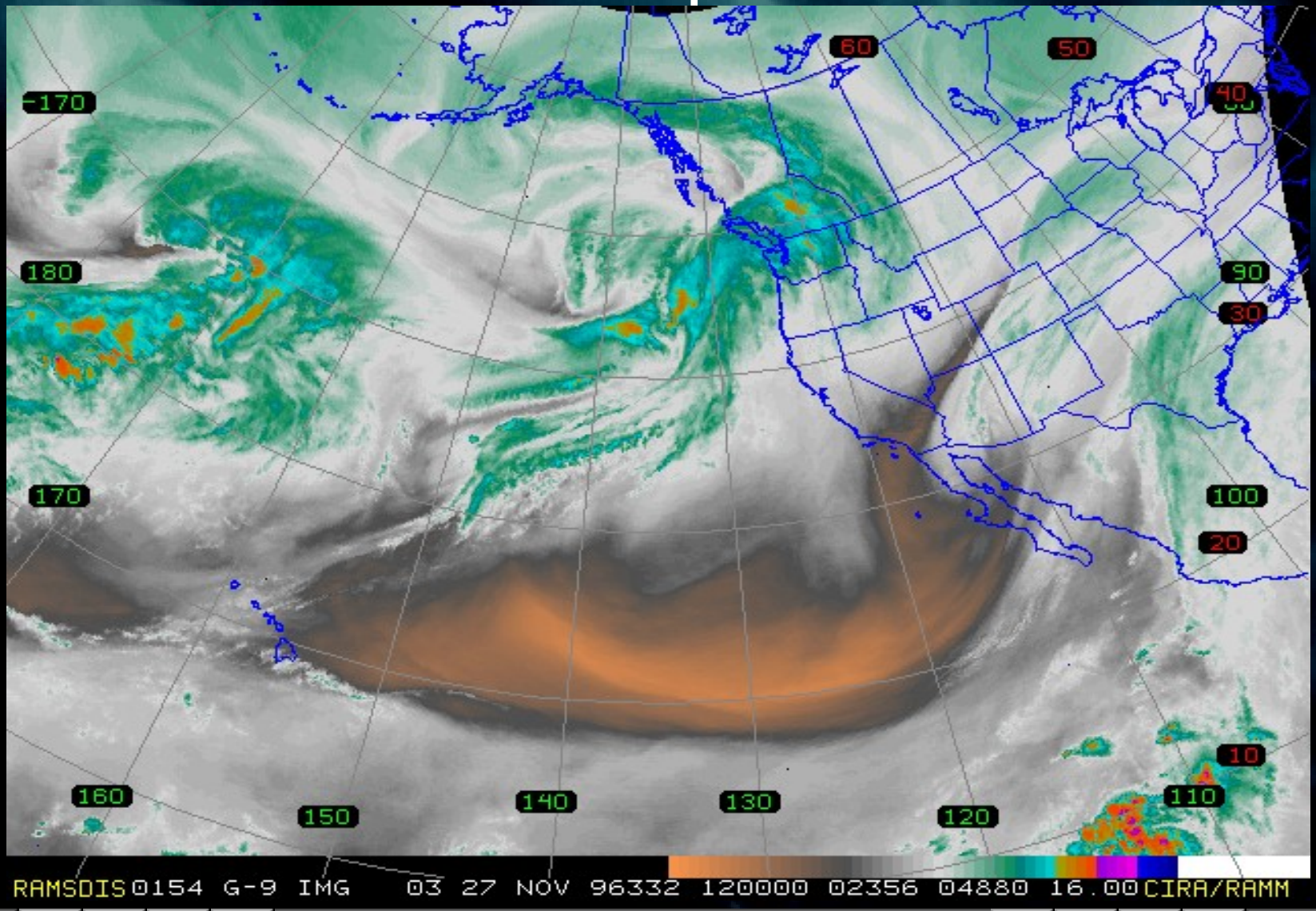
Water Vapor

- Advantages of WV imagery
  - It provides valuable information on upper-level flow where no clouds are present
  - WV imagery can provide a longer lead-time before a weather event occurs since the upper-level moisture pattern will change well before the surface weather changes

Water Vapor Image



Water Vapor Enhancement Curve Example



Review

- Satellite systems and imagery
  - Geostationary
  - Polar orbiting
  - Visual imagery
  - Infrared imagery
  - Water vapor imagery

Satellite Imagery

- Microwave Imagery
  - –Supplements conventional (VIS & IR) satellite
  - –Can give forecasters information about:

- Surface winds over broad areas of the oceans
- Rain rate
- Water vapor content
- Ice concentration and age
- Soil moisture
- Land surface characteristics
- Vegetation type

Microwave Imagery

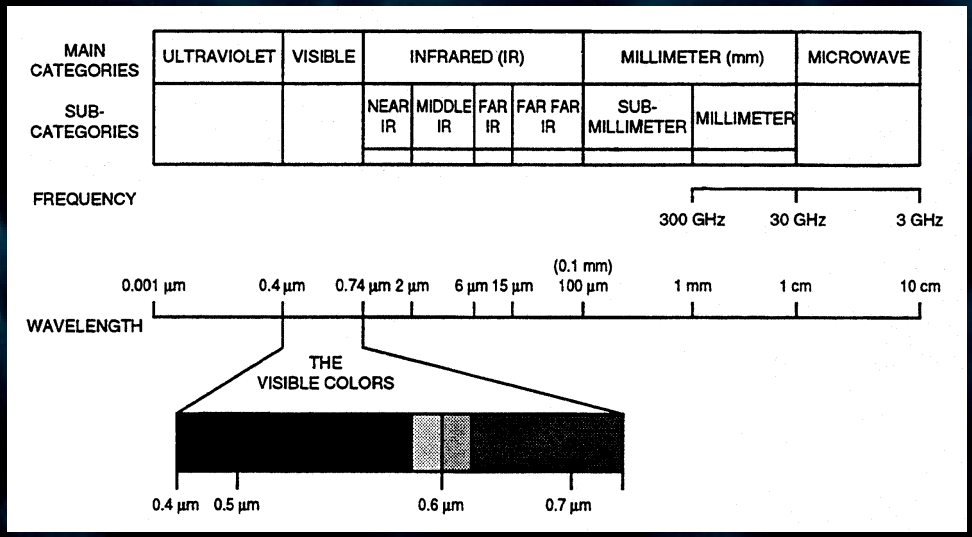
- Microwave theory
  - The earth and sun constantly emits microwave radiation
  - The sun's microwaves aren't normally reflected by the earth, but are instead absorbed
  - Therefore, we can assume all radiation coming up from the planet toward the satellite's sensor is *emitted* by the planet

Microwave Imagery

- Advantages
  - Constantly emitted (not reflected) from the earth
  - Several advantages of emitted radiation
    - No diurnal changes
    - No effects of sun angle
    - No confusing mix of emitted and reflected radiation which makes near infrared bands difficult to use

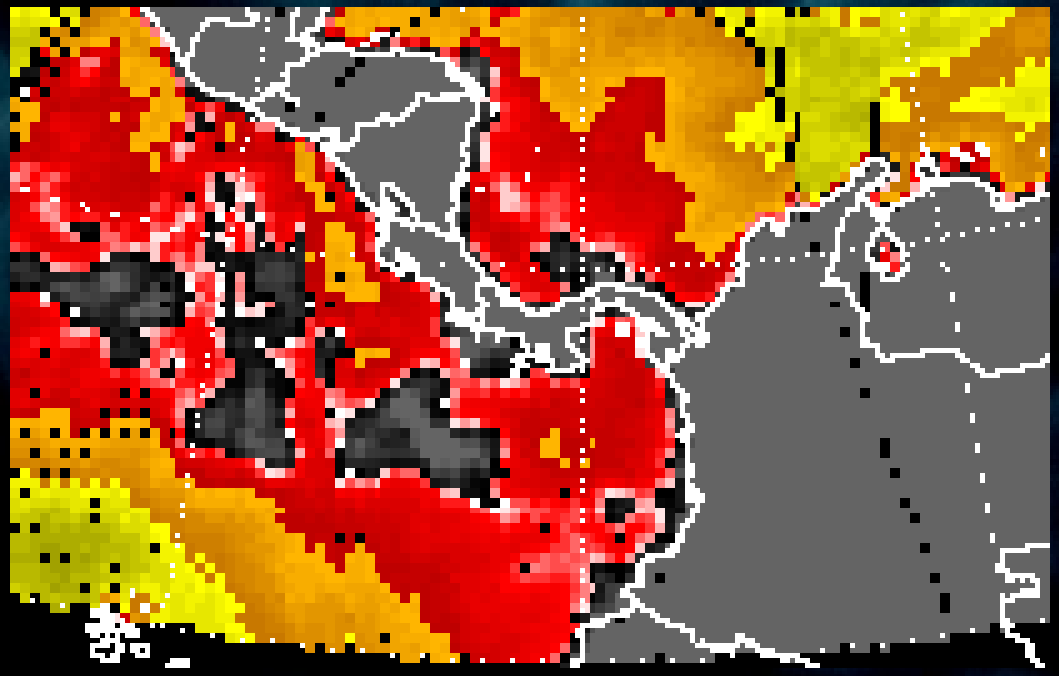
Microwave Imagery

- Longer wavelengths and lower frequencies
  - Wavelengths are between 1cm and 10 cm
  - Frequency is measured in gigahertz (GHz)
- Categorized by frequency



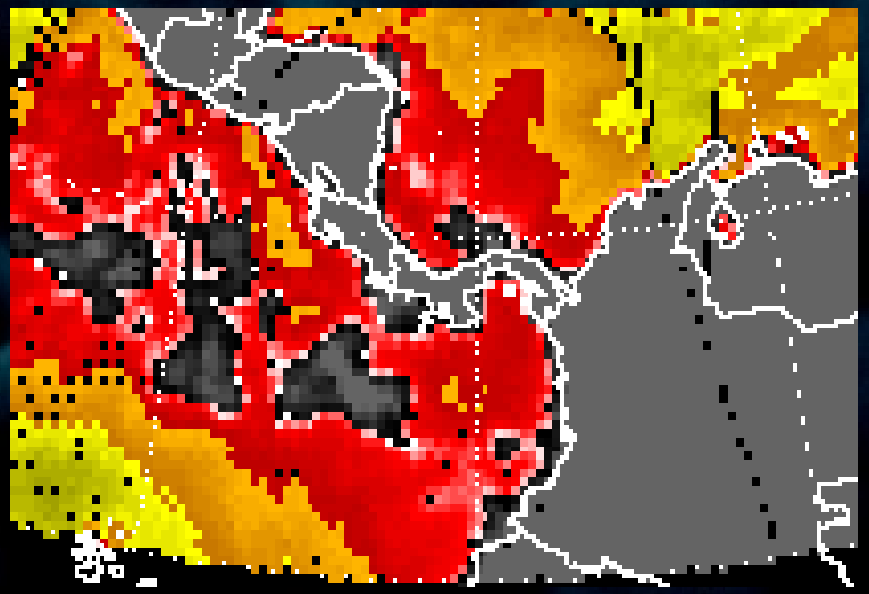
Microwave Imagery

- Due to longer wavelength, resolution is lower than visual and infrared imagery



Microwave Imagery

- Resolution is between 20 and 50 km
- Usually less attenuation (*signal loss*) in most microwave channels or frequencies
  - Microwaves penetrate clouds and vegatation
  - Ideal for surface monitoring



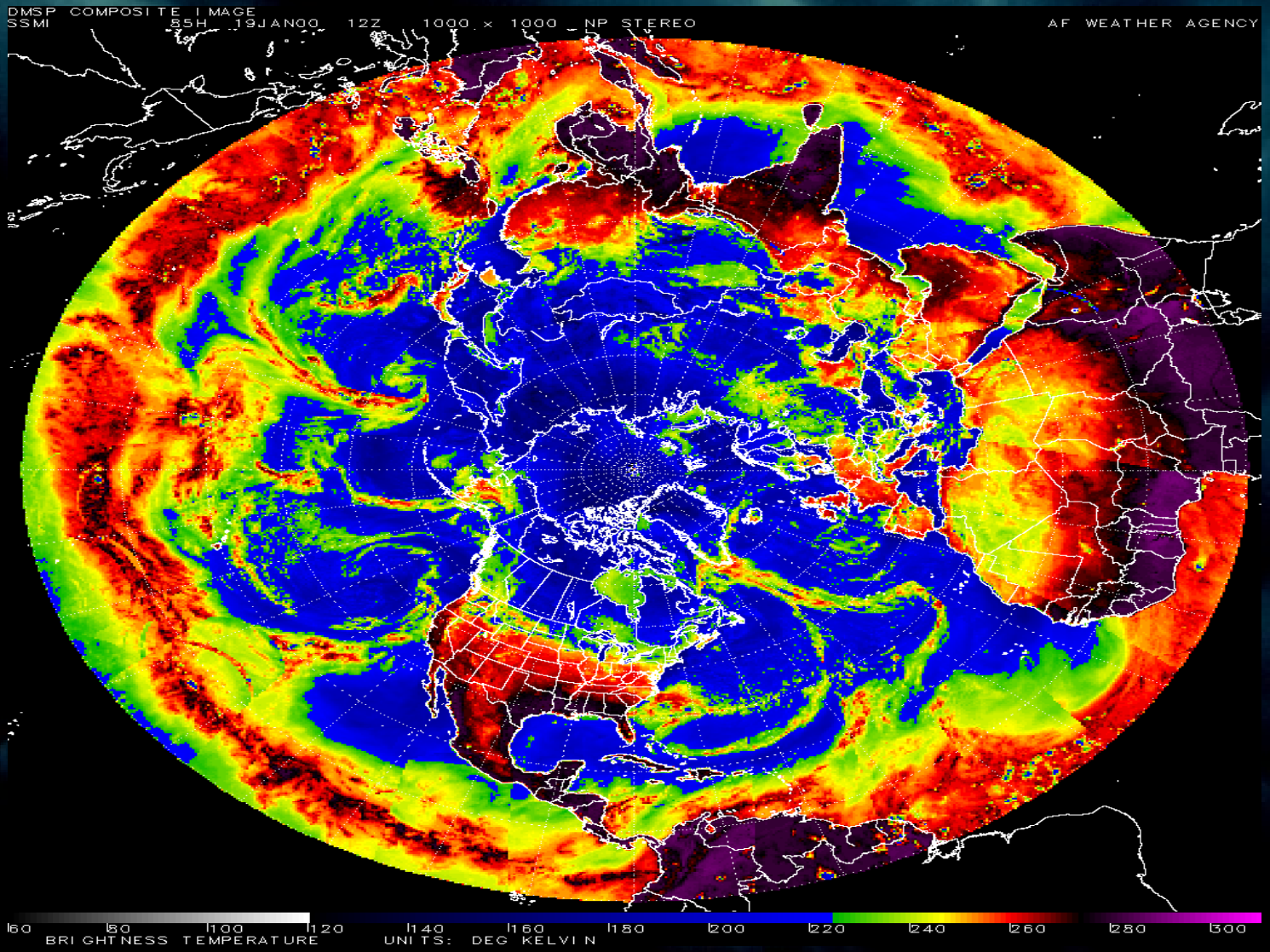
Microwave Imagery

- Microwave radiance variables
  - More variance then conventional bands
  - Radiance signatures
  - Sensors are used to note differences in the microwave radiance of these five variables
    - Frequency
    - Polarization
    - Emissivity
    - Transmissivity
    - Spatial uniformity

Microwave Imagery

- Frequency
  - Used to identify features on the surface or in the atmosphere
  - Depending on the feature frequency radiance may be constant or varying
  - Special sensor microwave imagery (SSM/I) sensors use four frequencies (channels):
    - 19, 22, 37, and 85 GHz

Microwave Animation

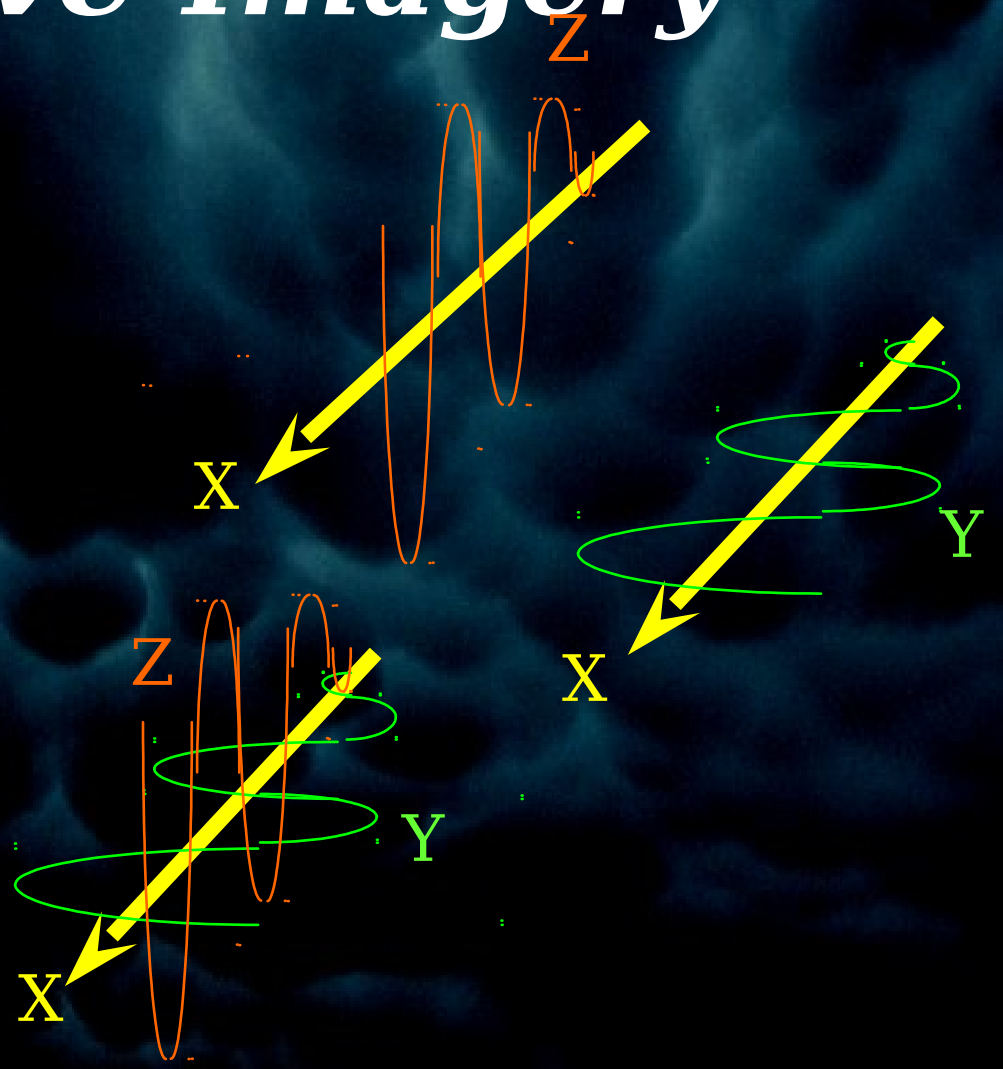

DMSP COMPOSITE IMAGE
SSMI 85H 19JAN00 12Z 1000 x 1000 NP STEREO
AF WEATHER AGENCY
160 180 100 120 140 160 180 200 220 240 260 280 300
BRIGHTNESS TEMPERATURE
UNITS: DEG KELVIN

Microwave Imagery

- Polarization
  - All radiation comes in packets of energy called photons
  - Most radiation is unpolarized with oscillating electric and magnetic fields
    - The photon’s electric field oscillates at right angles to the direction of motion
    - A magnetic field moving at right angles to the electric field

Microwave Imagery

- Polarization
  -- If radiation is polarized the photons will be aligned
  - Radiation from the surface is usually vertically polarized
  - Horizontally polarized radiation is oriented left to right



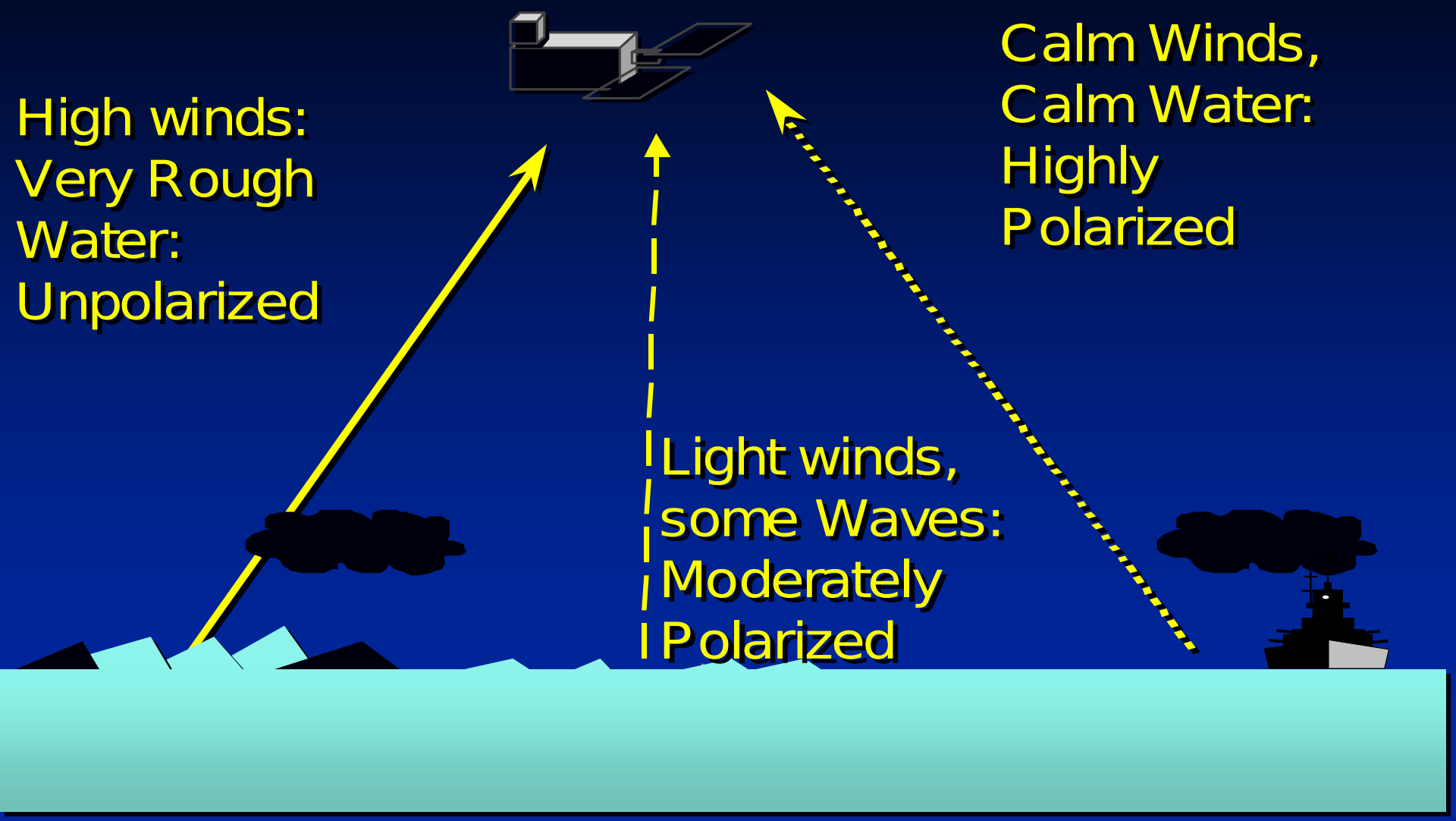
Microwave Imagery

- Polarization
  - Microwave sensors scan in a circular pattern at a look angle of 53° behind the satellite
  - Because of this, these sensors can discriminate between vertical and horizontal polarization in three of the four microwave frequencies it scans, for a total of seven channels

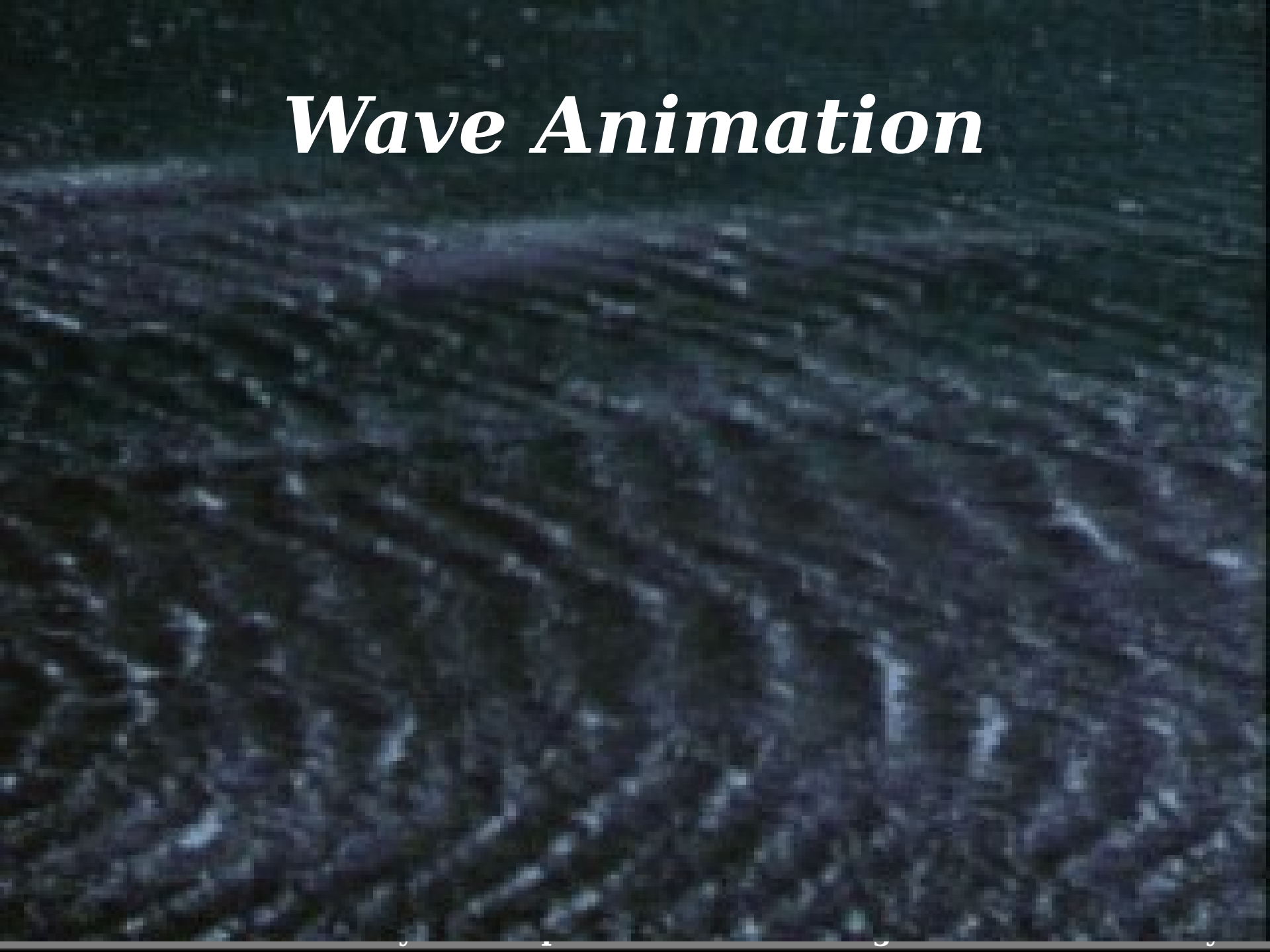
Microwave Imagery

- Polarization
  - Some objects emit or reflect a highly polarized signal
    - Calm seas emit vertically polarized signal
    - When seas become choppy the polarization difference decreases
    - Noting the change in polarization allows us to deduce the wind speed changes

Microwave Variables: Polarization Example



Wave Animation



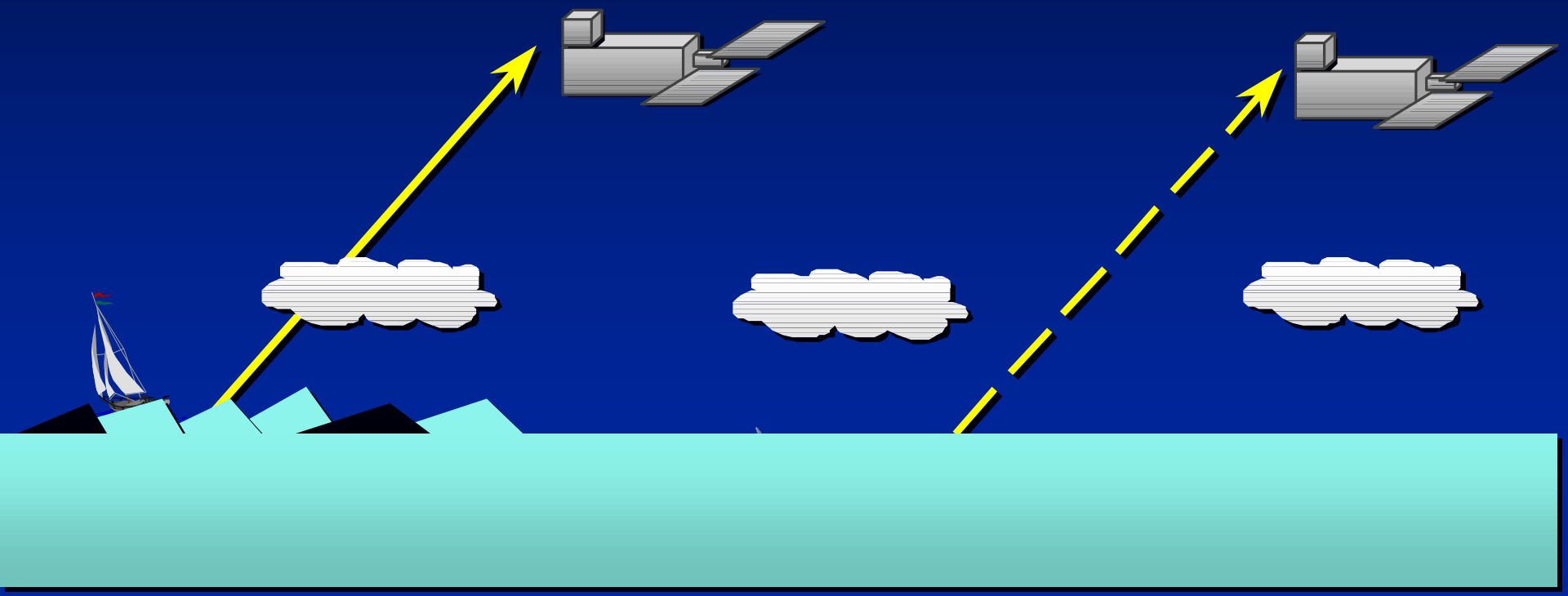
Microwave Imagery

- Emissivity(*amount of energy emitted by an object)*
  - Microwave emissivities of features on the earth and atmosphere vary significantly
    - This variable is the primary way microwave sensors differentiate features
  - Microwave sensed emissivities are low, but variances (*differences*) are significant
    - Clouds have higher emissivities while bodies of water have lower emissivities
  - Physical state of an object is also a factor when considering the differences in emissivity

Microwave Variables: Emissivity Example

Rough Water: Emissivity near 100%

Calm Water: Emissivity near 50%

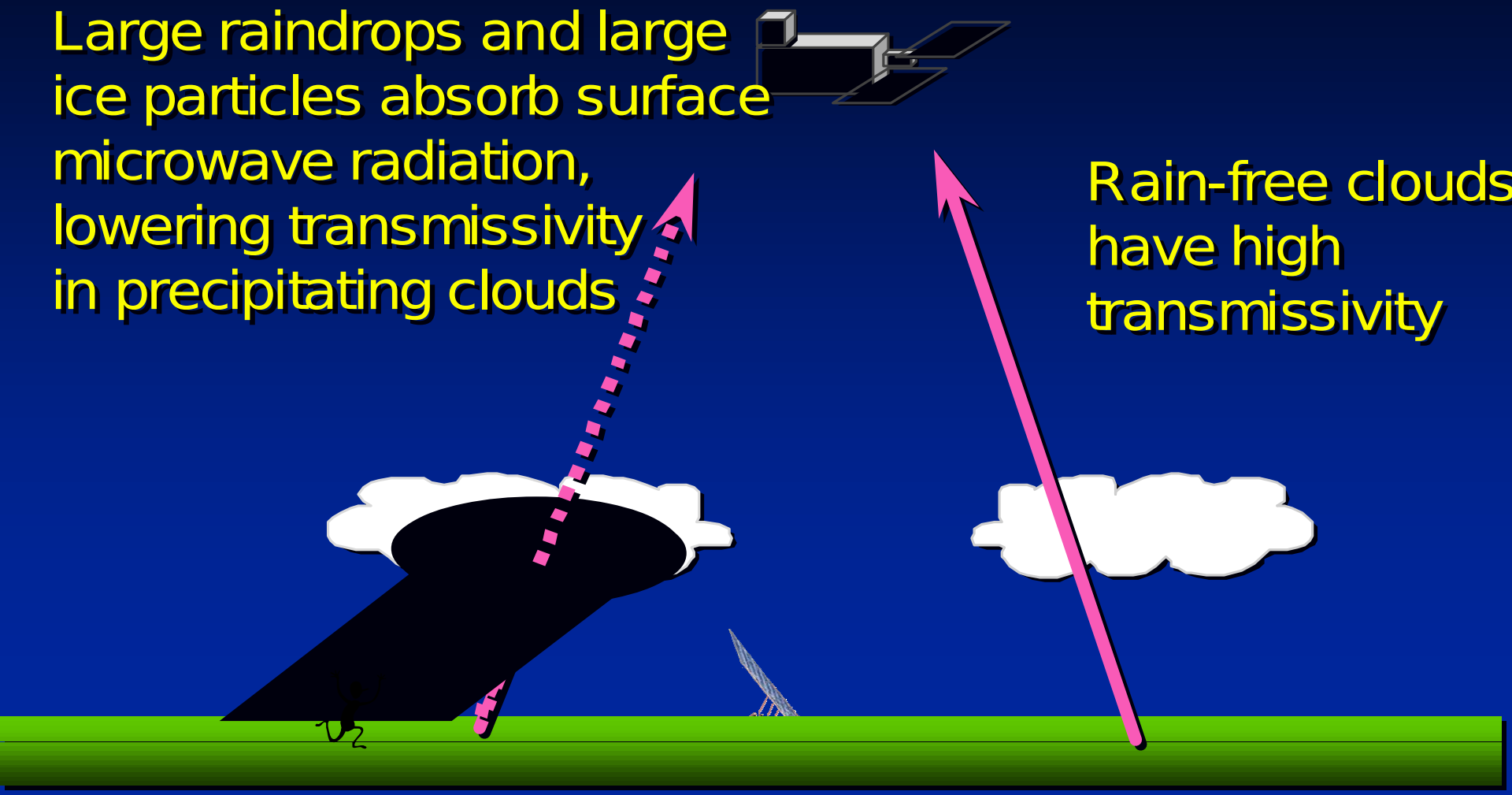


Microwave Imagery

- Transmissivity (*transparency*)
  - Can be used to identify a feature
  - Some frequencies are subject to attenuation (*signal loss*) by water vapor
  - The amount of attenuation (*signal loss*) can be correlated to atmospheric moisture
  - Cloud type and depth can be estimated

Transmissivity Example Precipitation

Large raindrops and large ice particles absorb surface microwave radiation, lowering transmissivity in precipitating clouds

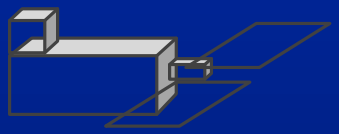


Rain-free clouds have high transmissivity

Microwave Imagery

- Spatial Uniformity
  - Land is very complex
  - Oceans are more uniform
  - Detecting precipitation over land is difficult
  - Algorithms are formed

Uniformity Example



Ice-free ocean: very uniform

Ocean with floating ice: low unifomity

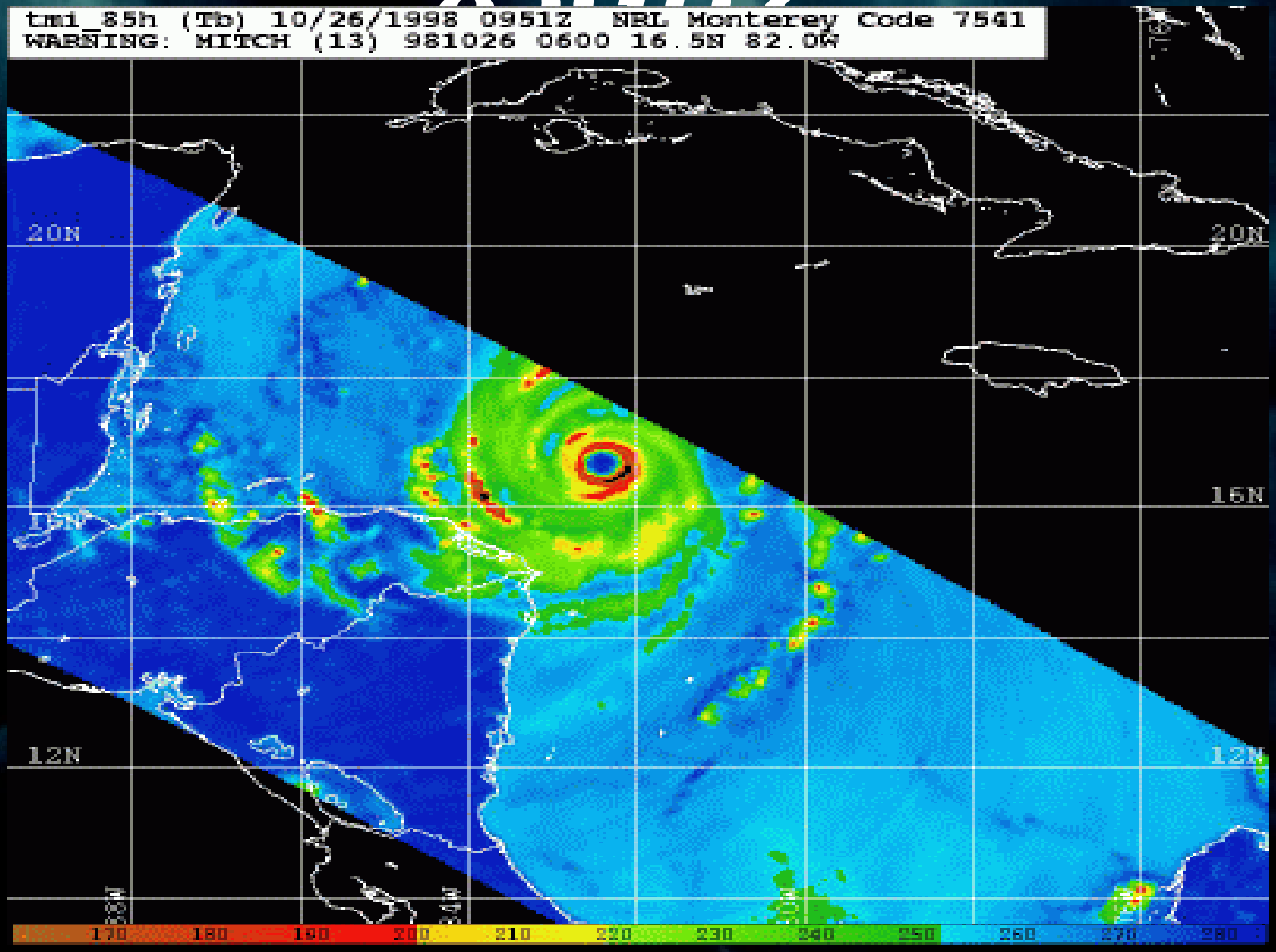
Microwave Imagery

- Raw Data Applications
  - Microwave sensors scan in four frequencies and distinguish between horizontal and vertical polarization in three of the four frequencies
  - Older days can only show brightness temperatures in various frequencies
  - Therefore, the higher the brightness temperatures, the higher the emissivities

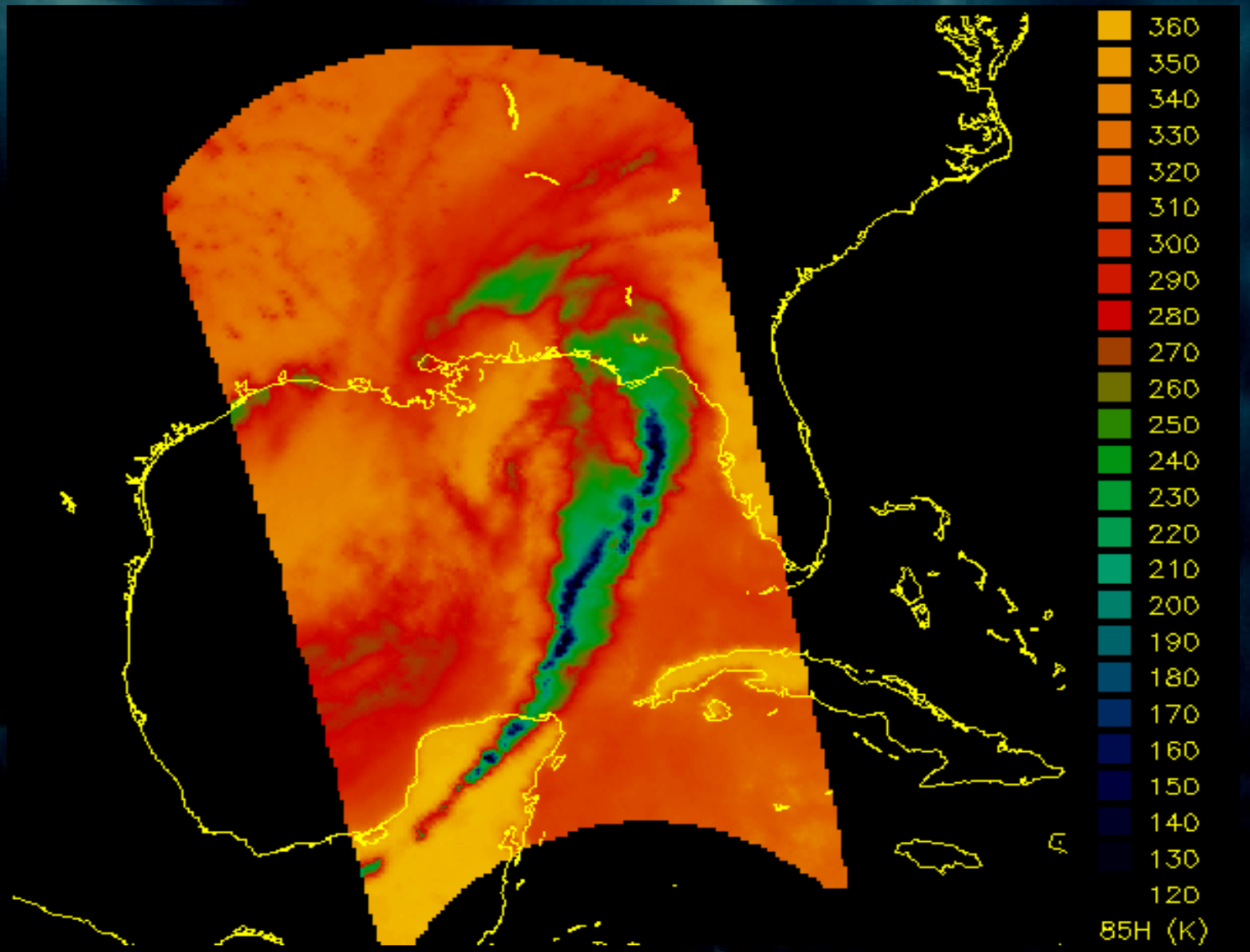
Microwave Imagery

- 85 GHz Frequency
  - Sensitive to suspended water droplets and ice particles, but not ice crystals
  - Reveals low and middle clouds and precipitation, even through cirrus overcast
  - Use 85H to locate oceanic stratiform clouds and precipitation at night over relatively calm oceans
  - Allows distinction between convection and cirrus overcast (good for identifying tropical cyclone rain bands, eyes and eye wall organization.)

Microwave Imagery-85GHz



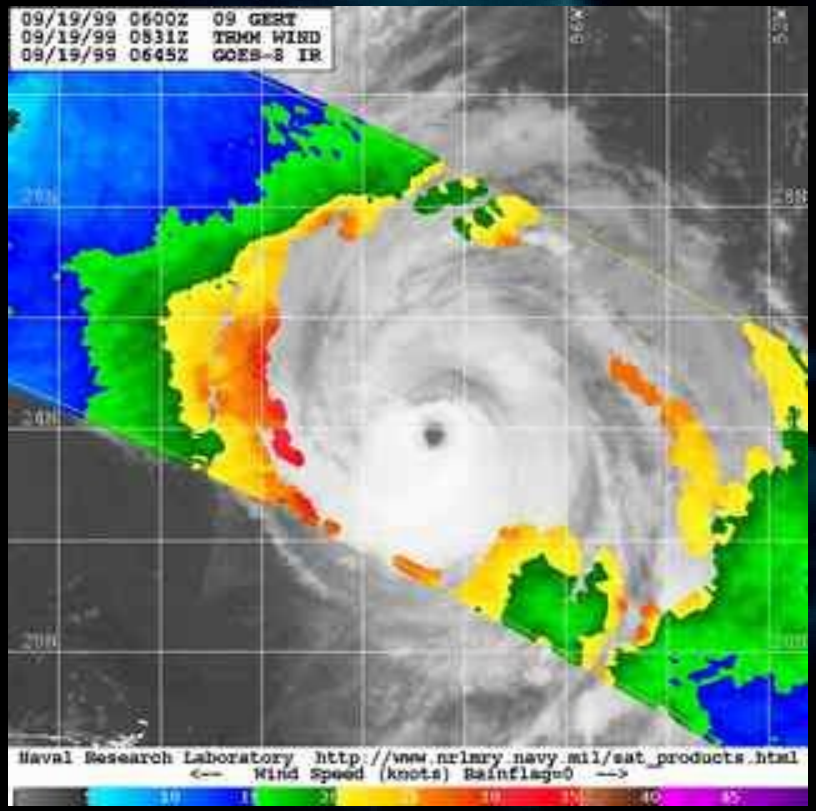
Microwave Imagery- 85G

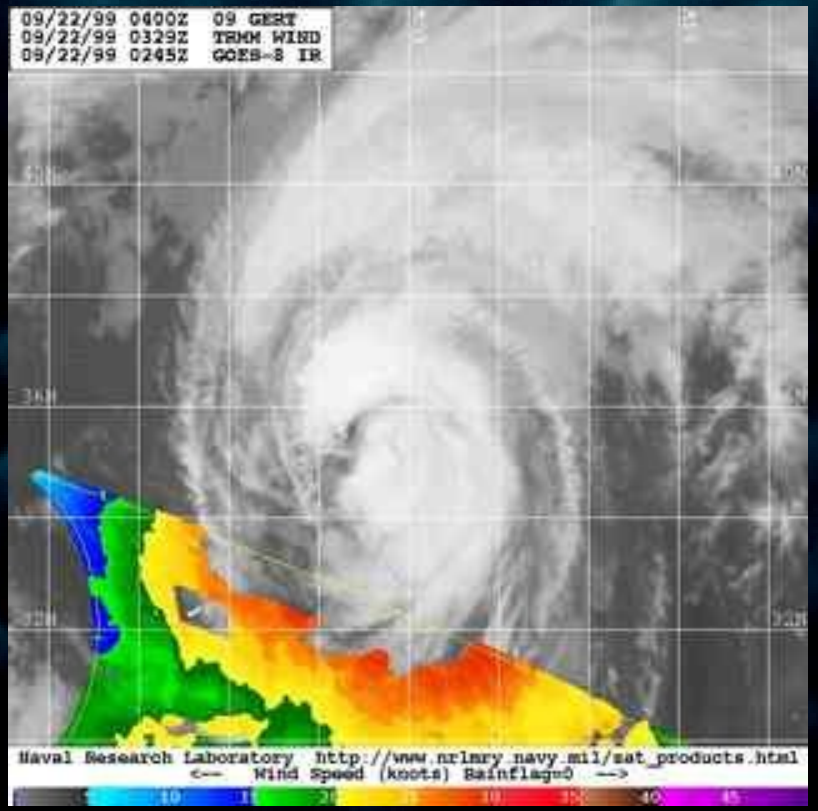


Microwave Imagery

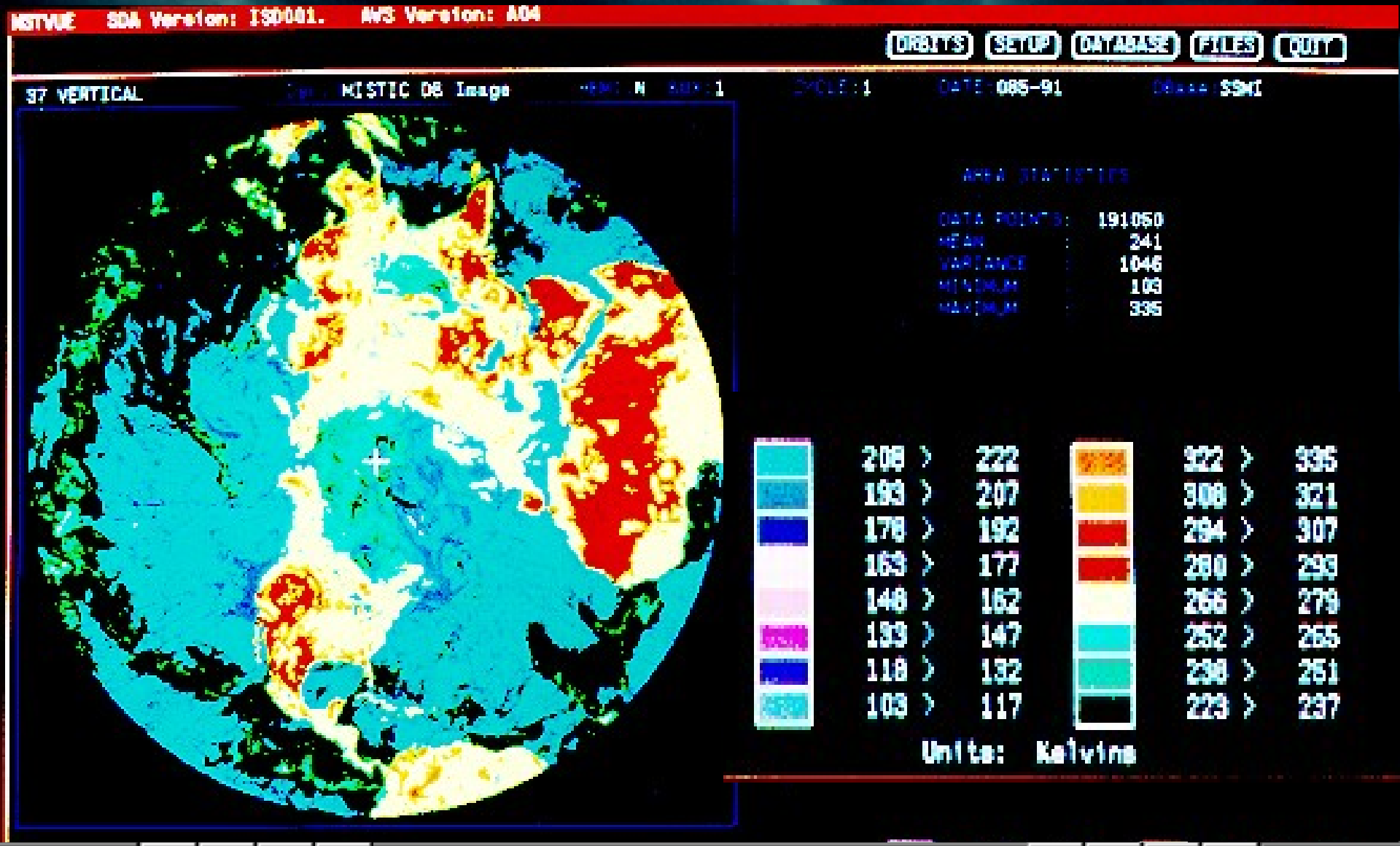
- 37 GHz Frequency
  - Used mostly in identifying snow and wind speeds
  - Used to determine sea state - a reduction in polarization relates to higher seas and increased surface wind. (Multi-spectral subtraction : 37V-37H)
  - Technique restricted to clear ocean areas at least 50 nm from coastlines

37Ghz TRMM - 37 GHz

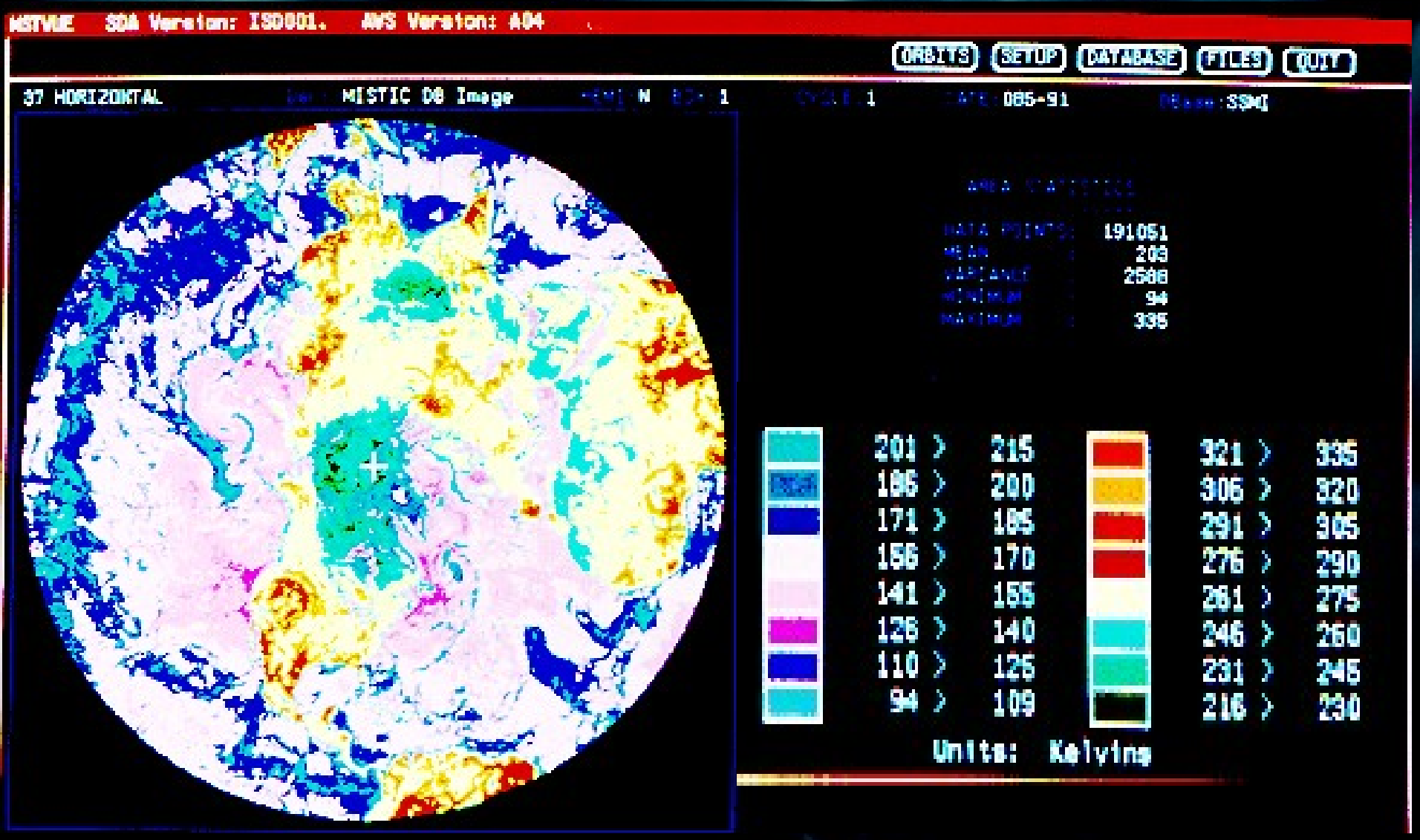




37Ghz V Raw Data



37Ghz H Raw Data



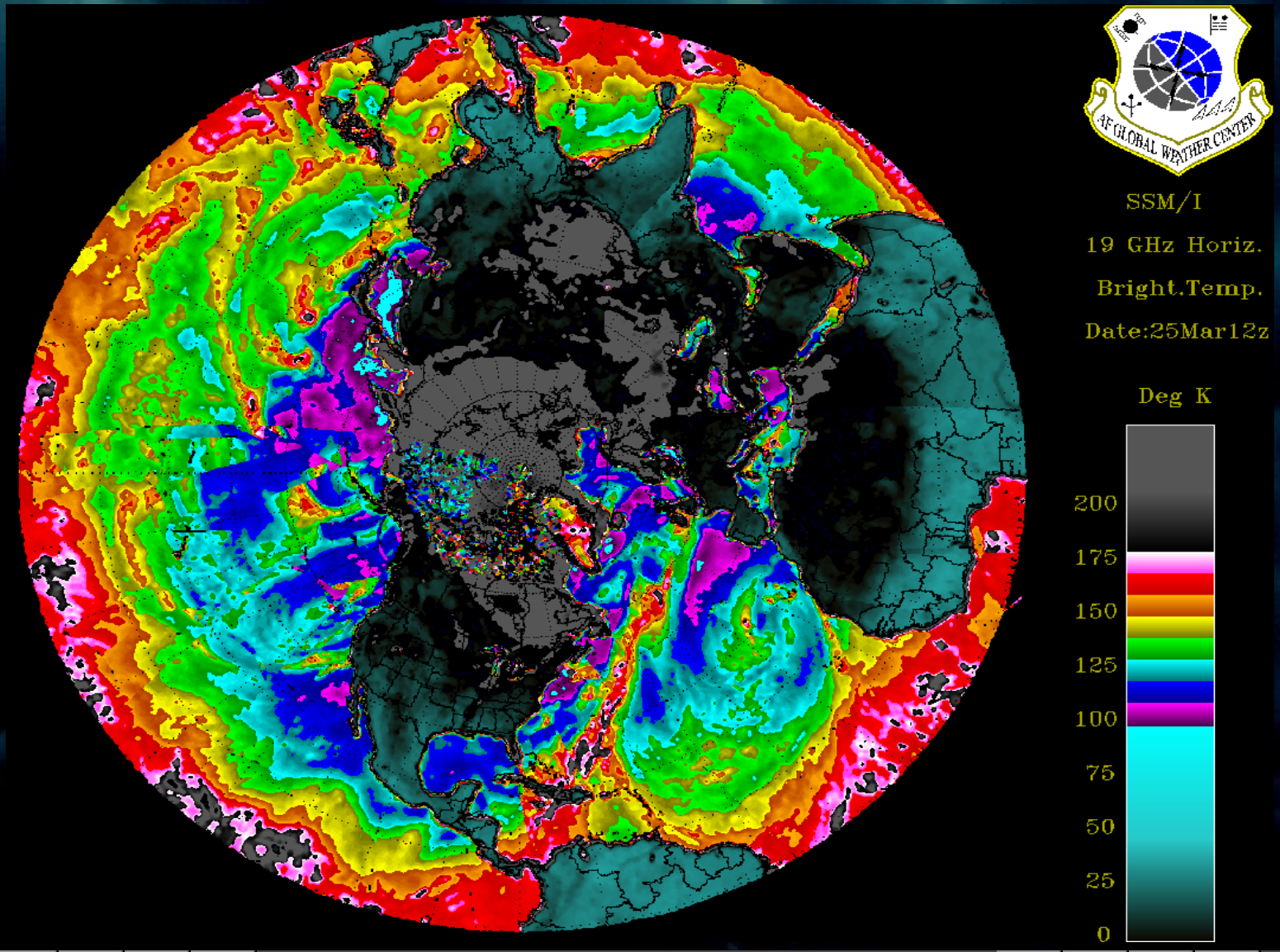
Satellite Imagery

- 22.235 GHz Frequency
  - This frequency was chosen because water vapor absorbs well in it
  - It emits well in the wavelength, and so it is used like the water vapor channel. IR

Satellite Imagery

- 19 GHz Frequency
  - Emissivity of water: very low; land:high
  - Reveals areas of standing water
    - traffic ability for troops
  - Access sea surface winds

19Ghz raw data



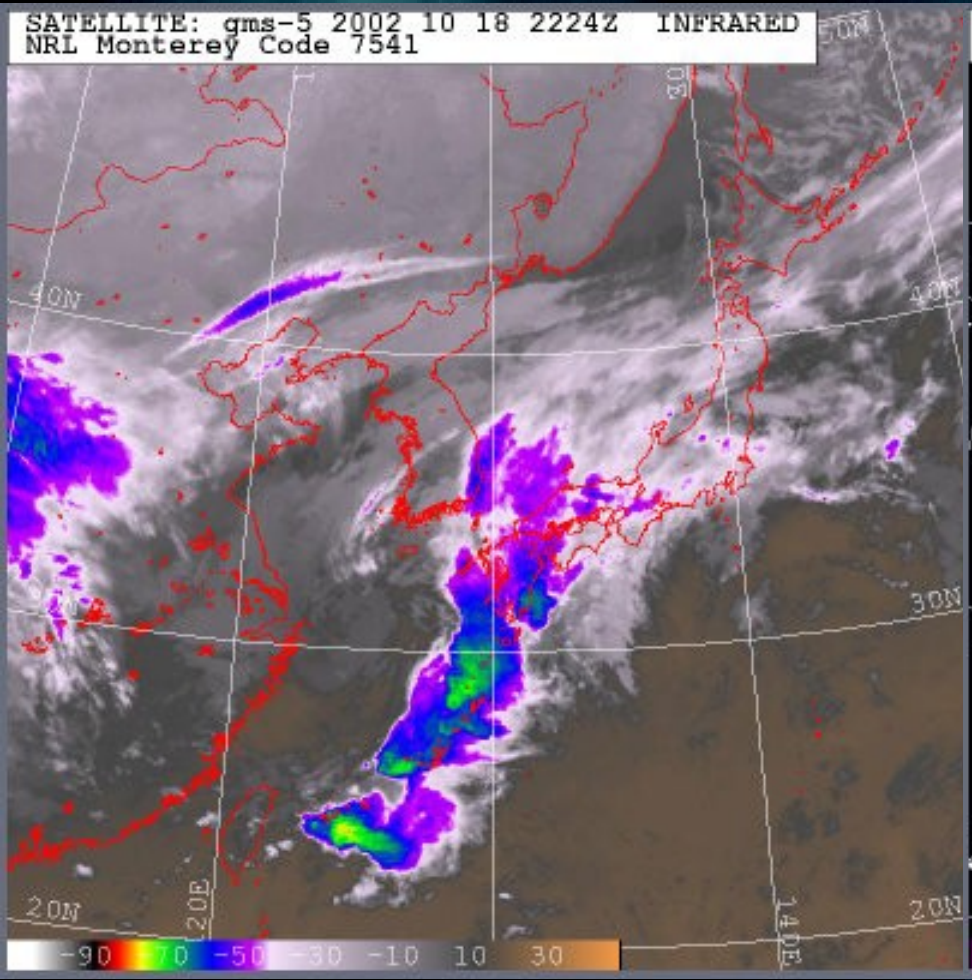
Satellite Imagery

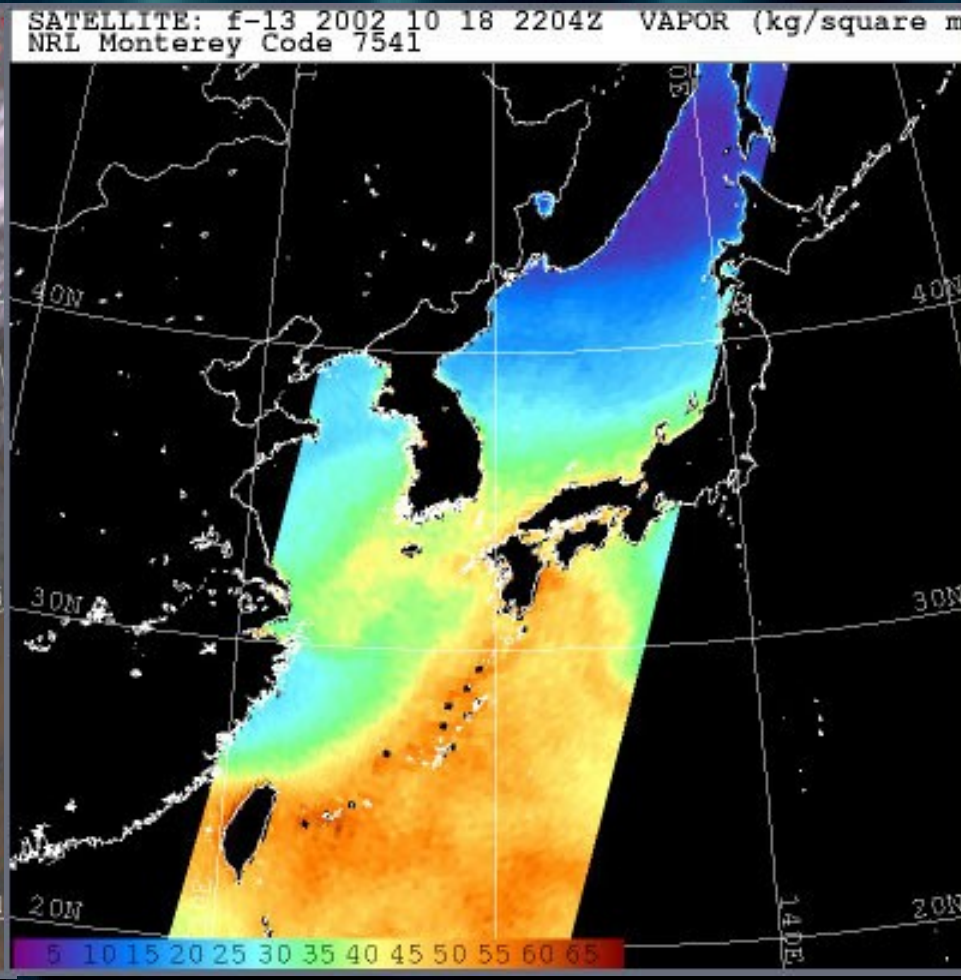
- Derived Products
  - Products of Algorithms
  - Do not assume always correct!!!!!

Satellite Imagery

- Integrated Water Vapor
  - Good for visibility and moisture for convection
  - Use over large bodies of water (away from coastlines)
  - Rain is flagged
  - Caution where contamination occurs

IWV Derived product

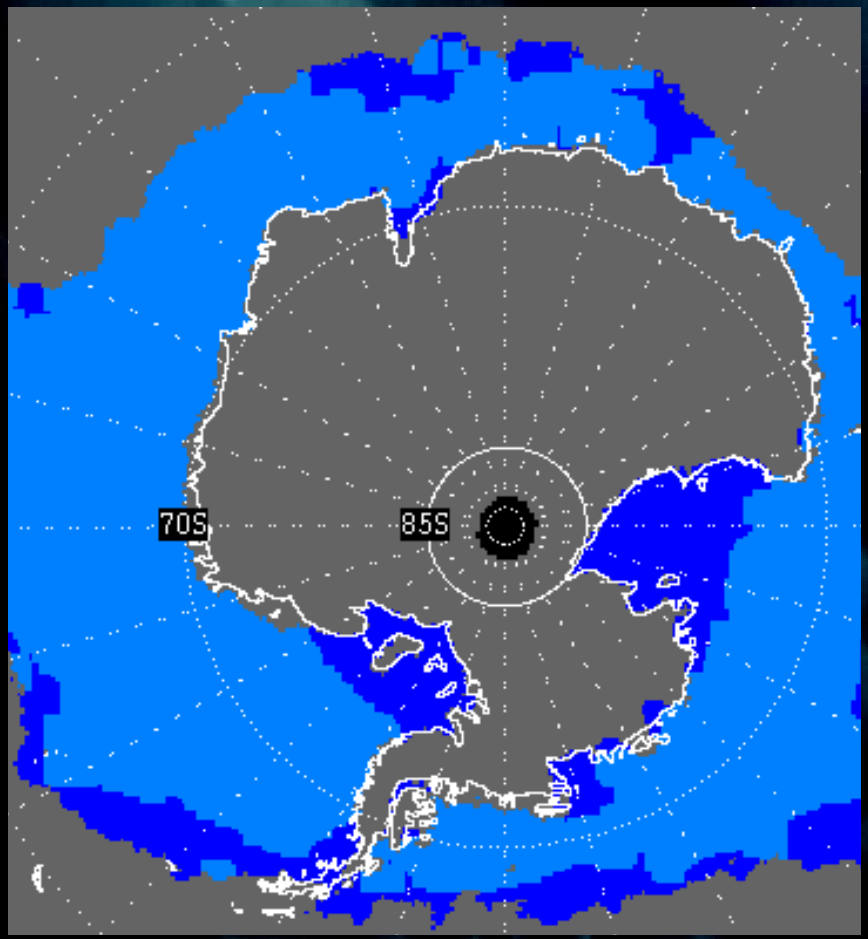


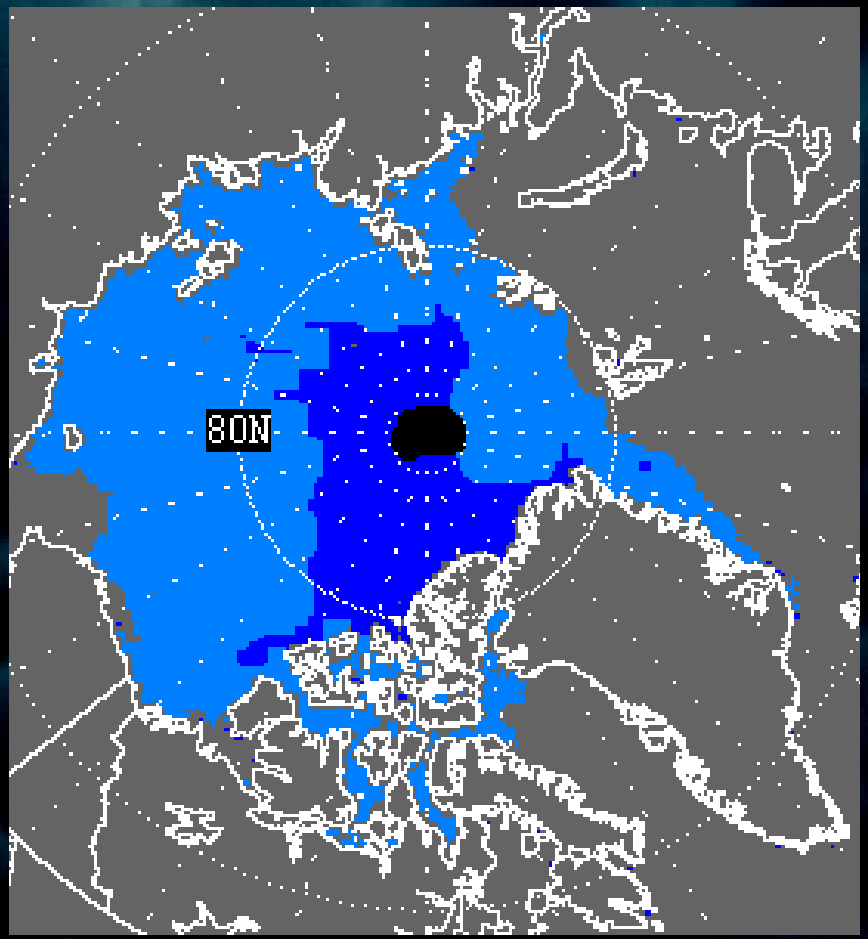


Satellite Imagery

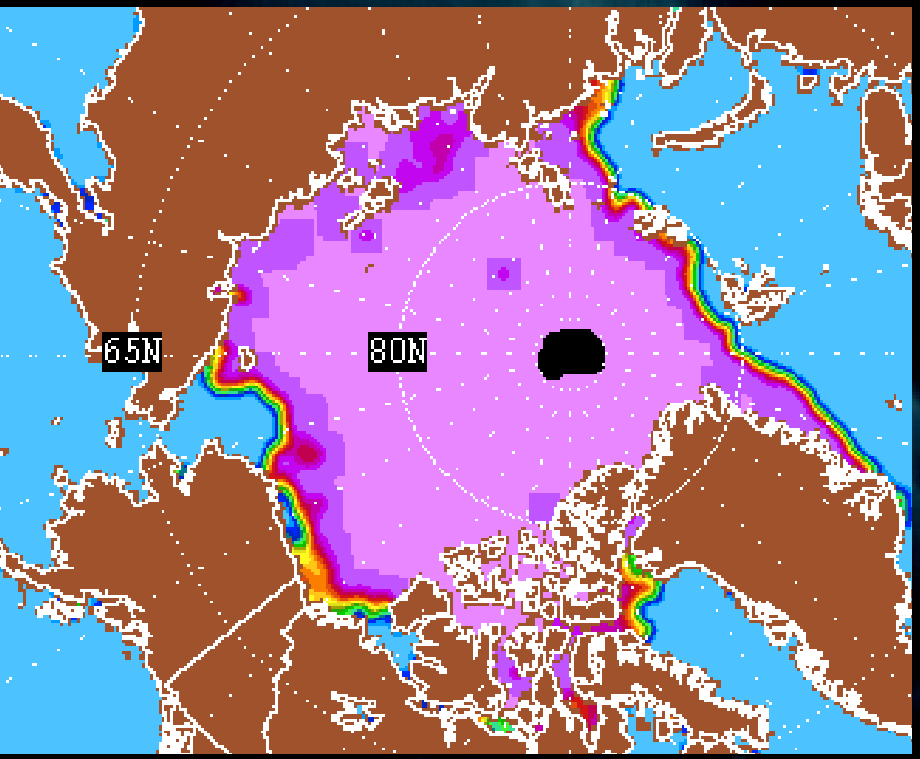
- Sea Ice Coverage and Ice Age
  - Amount and age of ice
    - Ship traffic ability
  - Ice edge and land not calculated
  - Difficult to use during the melt season

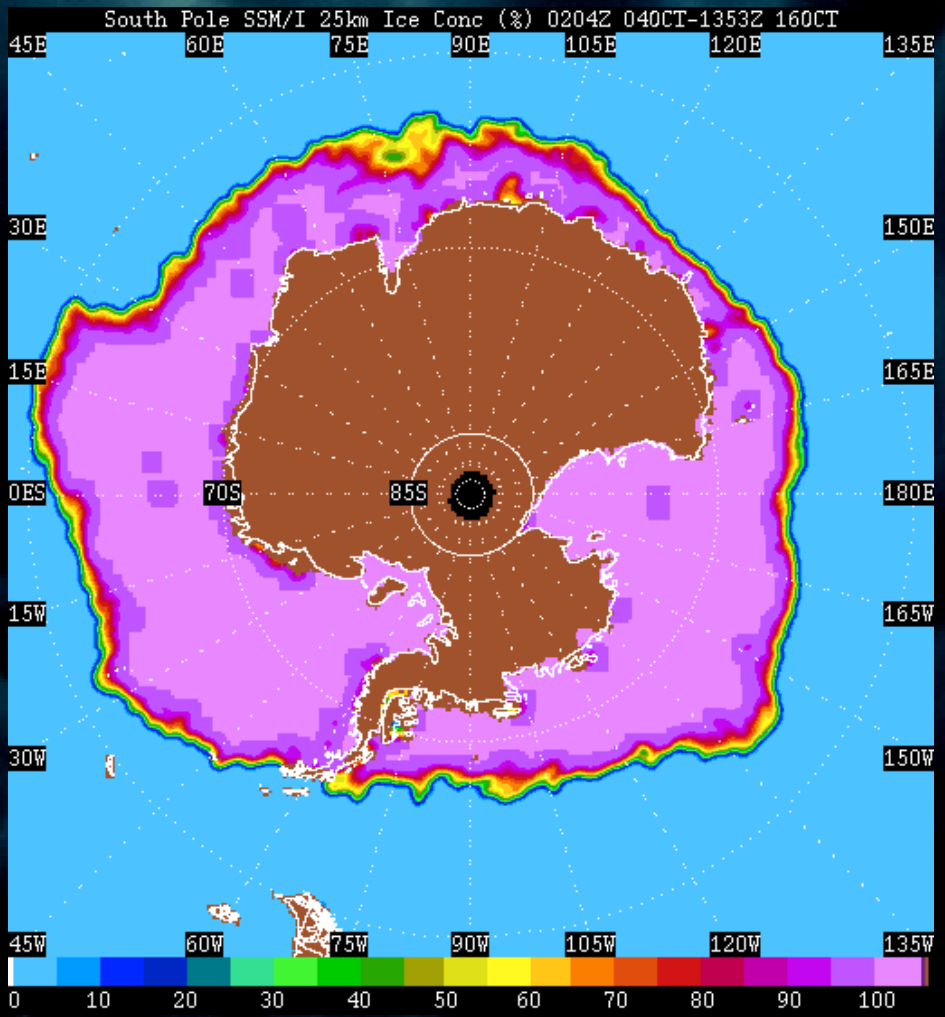
Ice Age





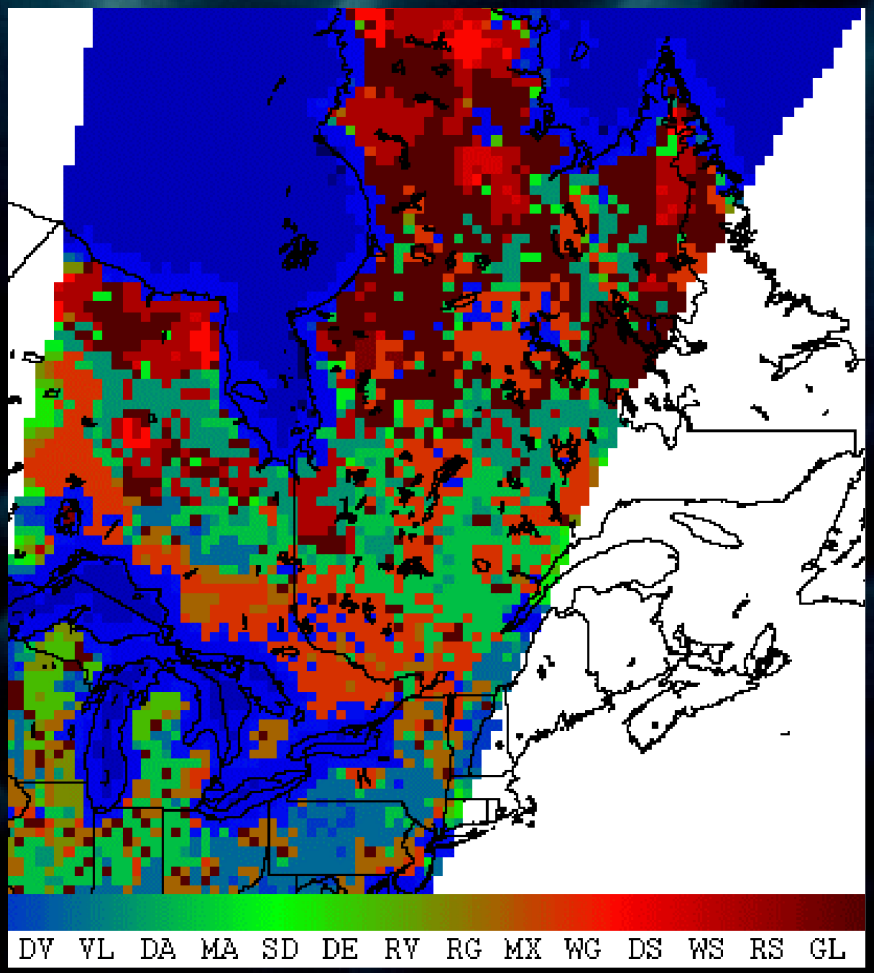
Sea Ice


65N
80N


South Pole SSM/I 25km Ice Conc (%) 0204Z 04OCT-1353Z 16OCT
45E
60E
75E
90E
105E
120E
135E
30E
150E
15E
165E
0ES
70S
85S
180E
15W
165W
30W
150W
45W
60W
75W
90W
105W
120W
135W
0
10
20
30
40
50
60
70
80
90
100

Surface Characteristics Algorithms

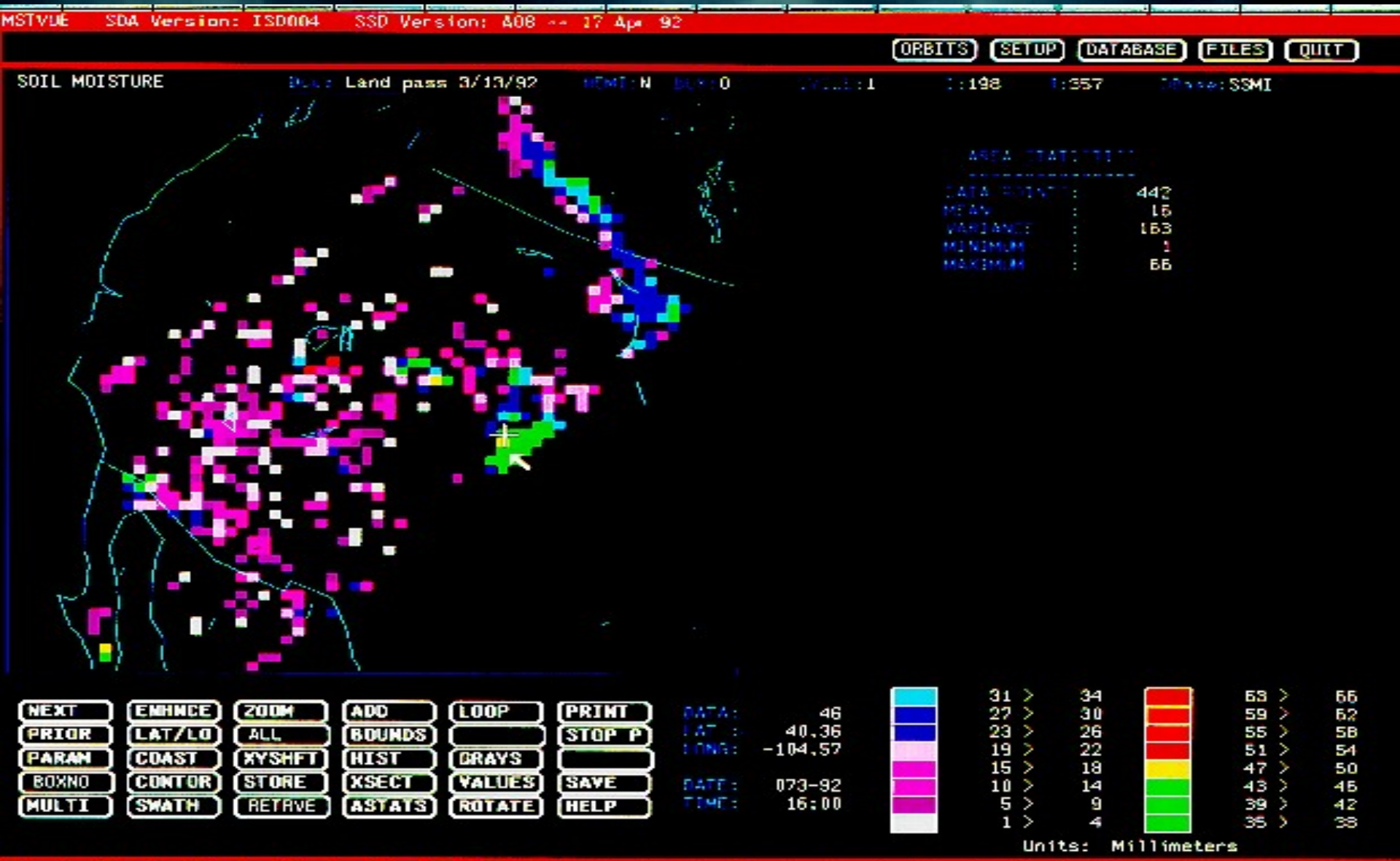
- Still improving techniques
- Used for assessment for traffic ability of troops, vehicles
- Not widely used at this time



Satellite Imagery

- Soil Moisture Algorithms
  - Recent precipitation indicator
  - Values given in percentages
    - 100% is a flooded area
  - How much rain has fallen
    - Troop traffic ability

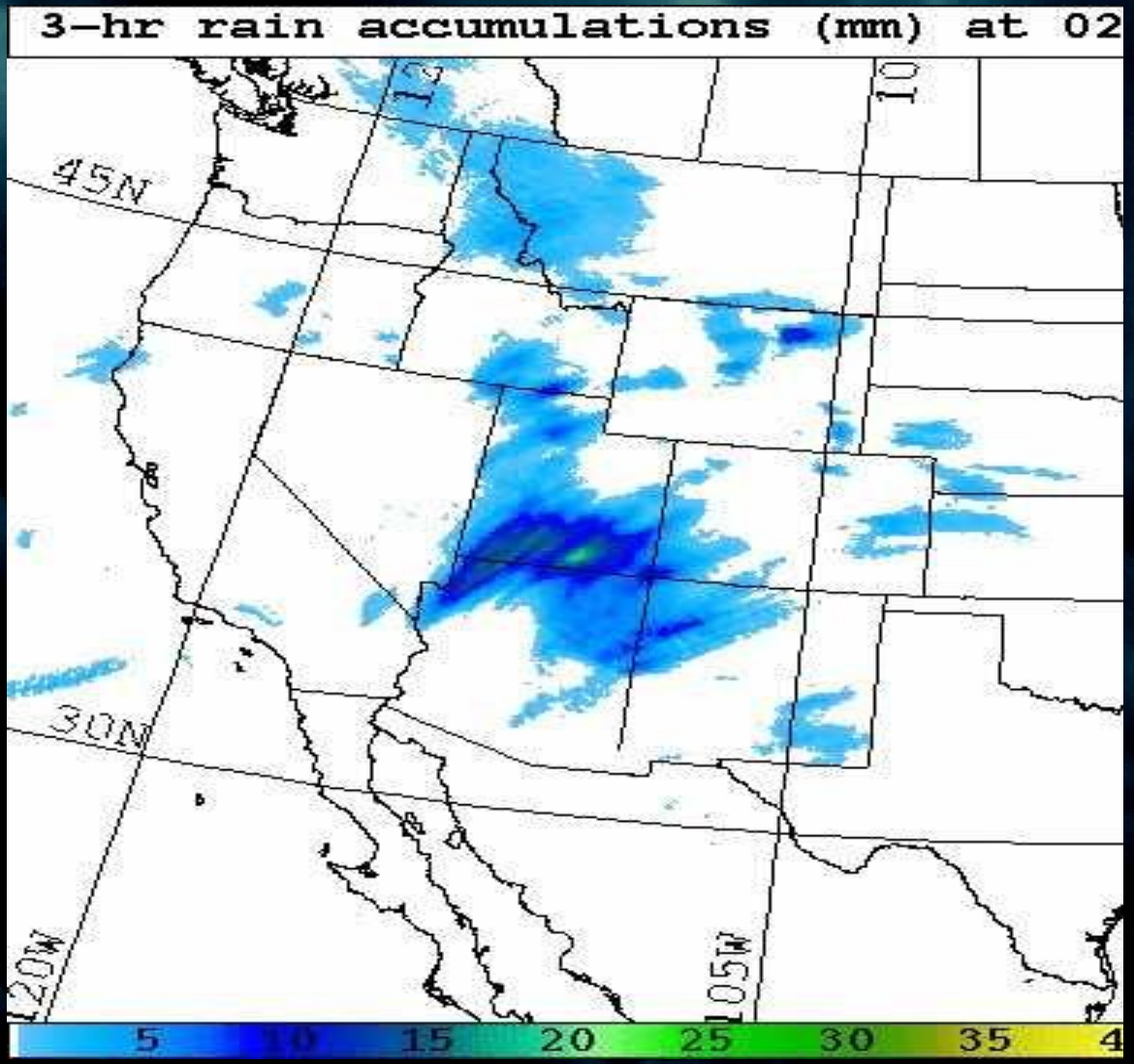
Soil Moisture



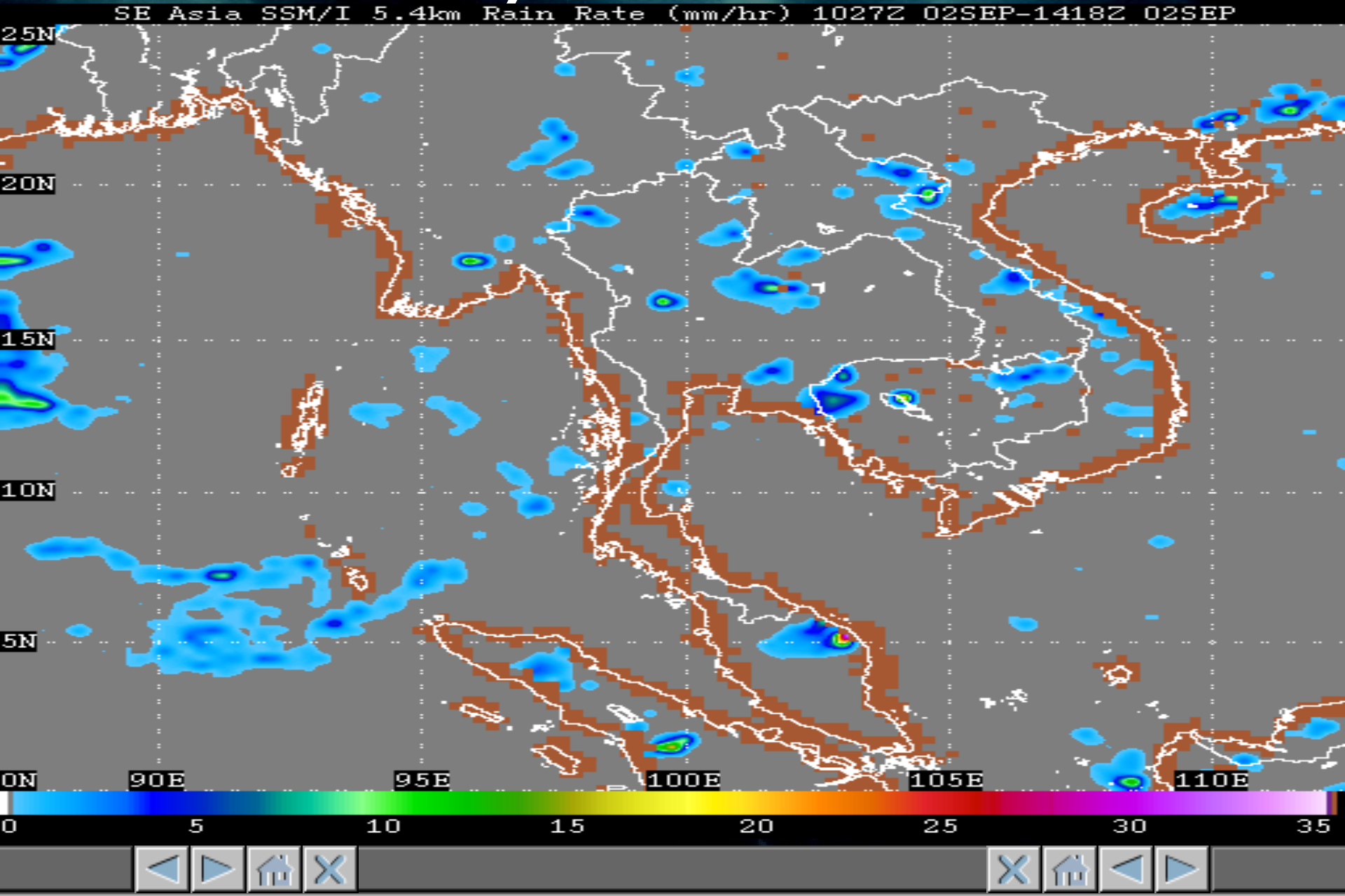
Satellite Imagery

- Rain Rate
  - Land and water algorithms differ
  - Small non-convective rainstorms
    - Only seen over oceans
    - Higher clouds and choppy water make less valid
  - Large convective storms are found anywhere
  - Resolution problems
    - Rain-free and heavy rain areas averaged
    - Estimations lower then actual

IR Rain Rate


3-hr rain accumulations (mm) at 02
45N
30N
120W
105W
5
10
15
20
25
30
35
4

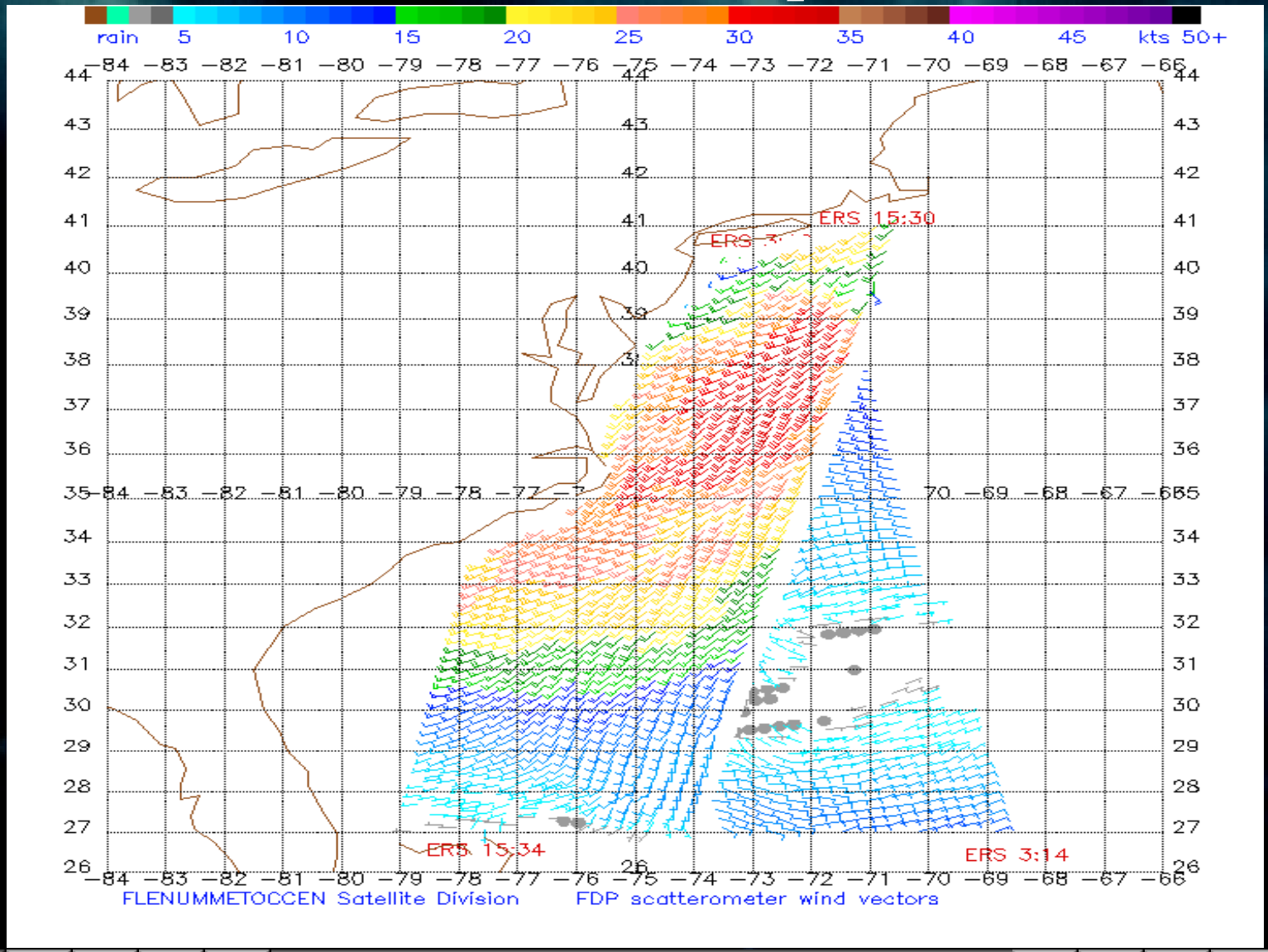
SSM/I Rain rate



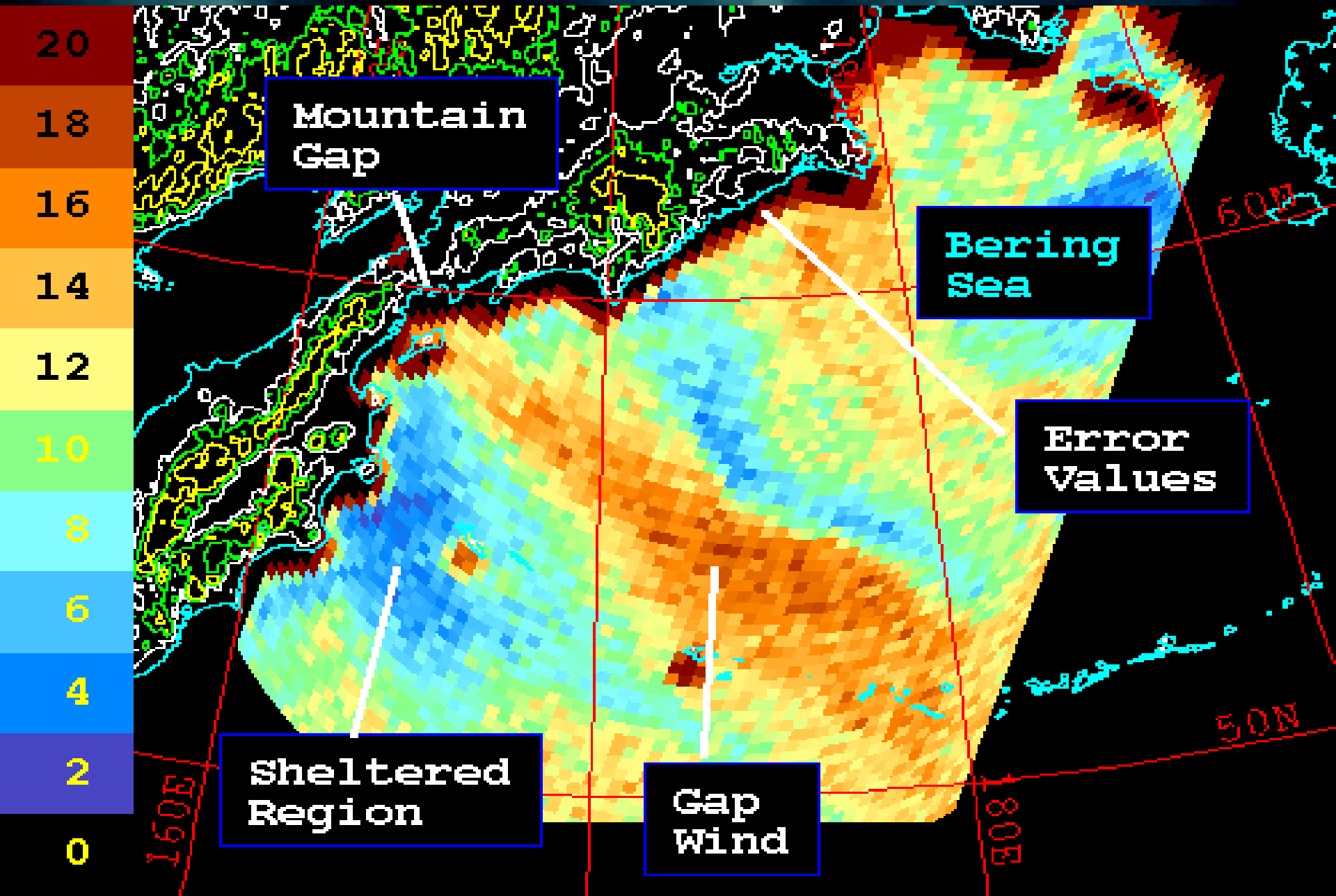
Satellite Imagery

- Surface Wind Algorithms
  - Depends on reduction of polarization with sea surface roughness
  - Degraded by
    - Precipitation and land surfaces
    - Low and mid level clouds (smaller effect)\
    - Winds greater then 30 knots
    - Thick clouds and precip are flagged to use caution
  - Very accurate on clear oceans,few clouds, and LT to Mod winds

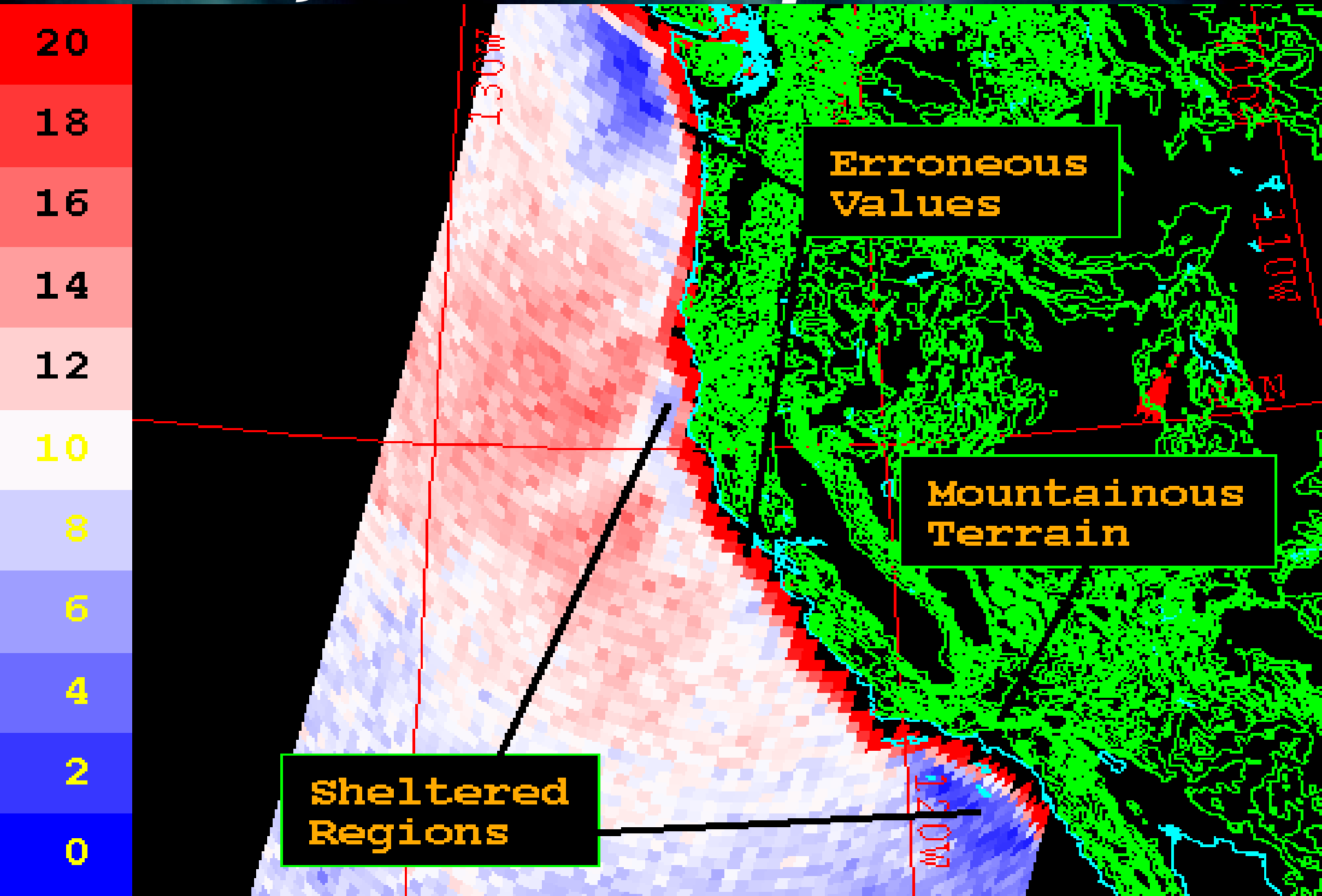
Surface Wind products


rain 5 10 15 20 25 30 35 40 45 kts 50+
ERS 15:30
ERS 15:34
ERS 3:14
FLENUMMETOCCEN Satellite Division
FDP scatterometer wind vectors

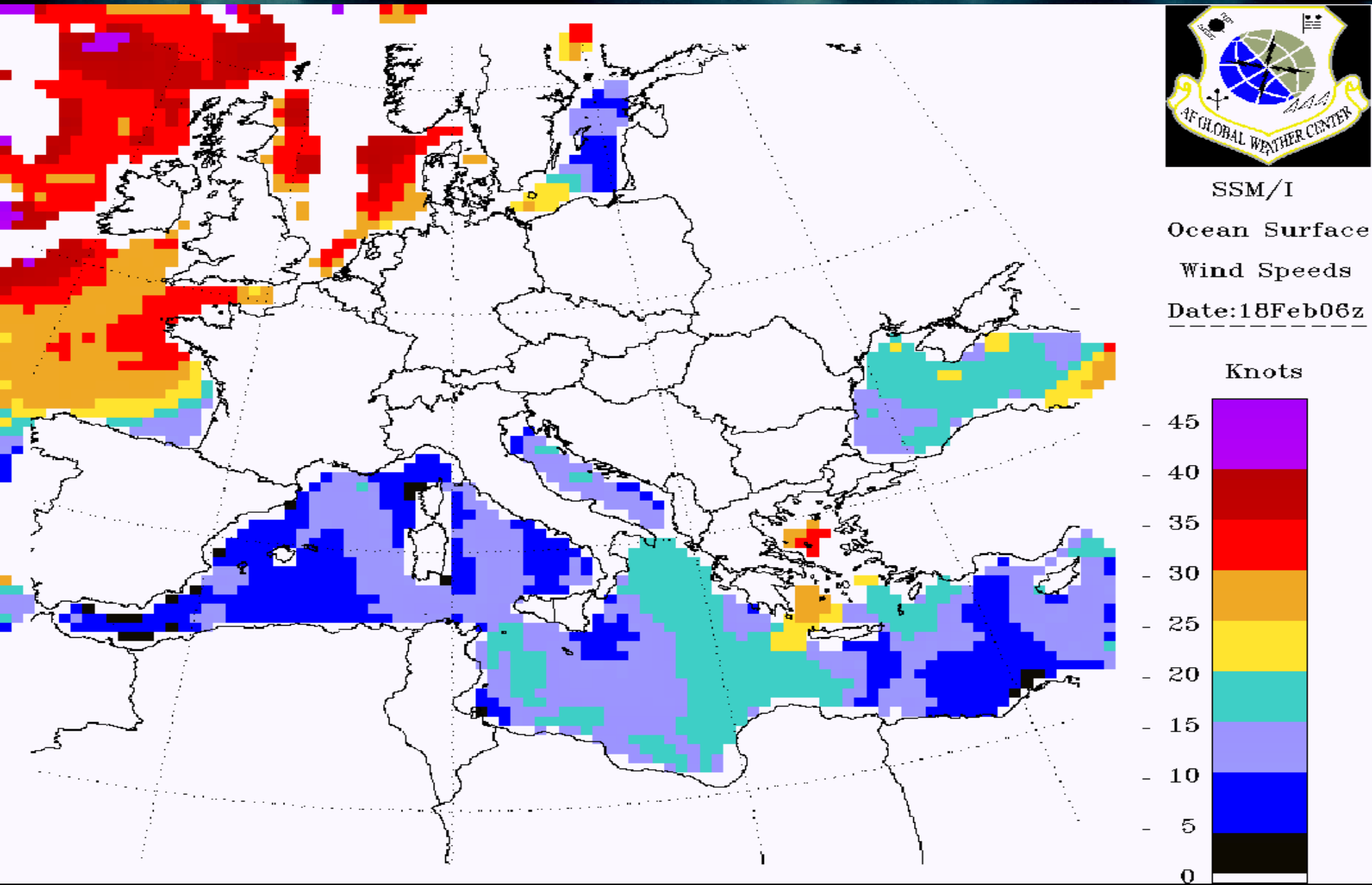
Surface Wind products



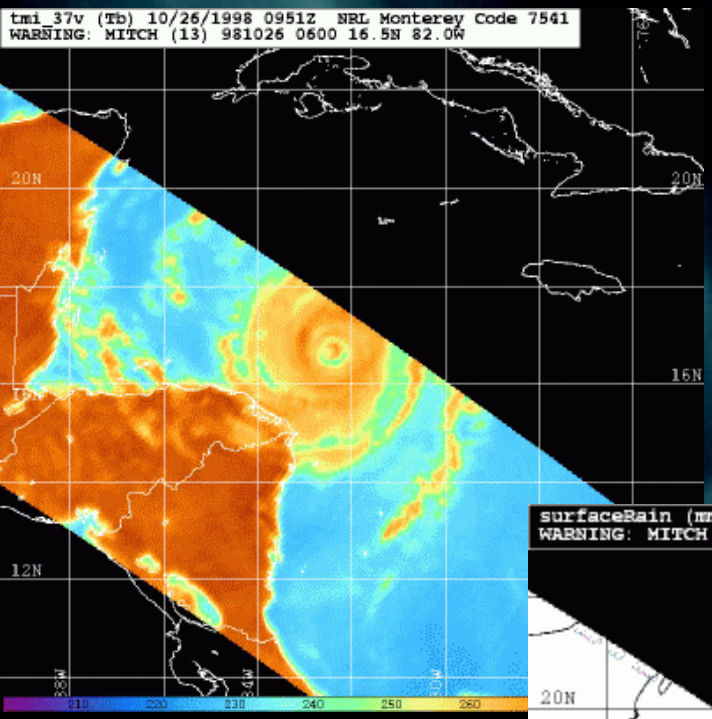
Surface Wind products

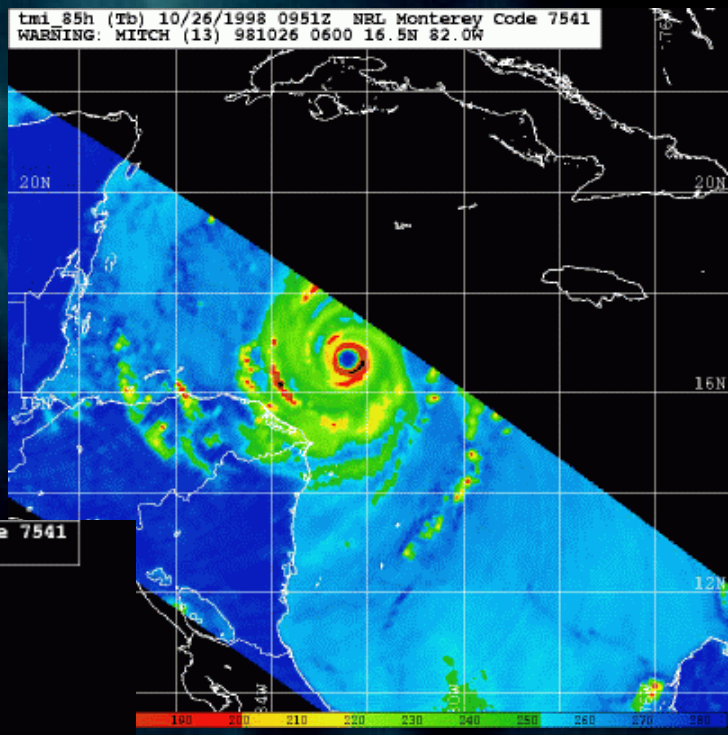


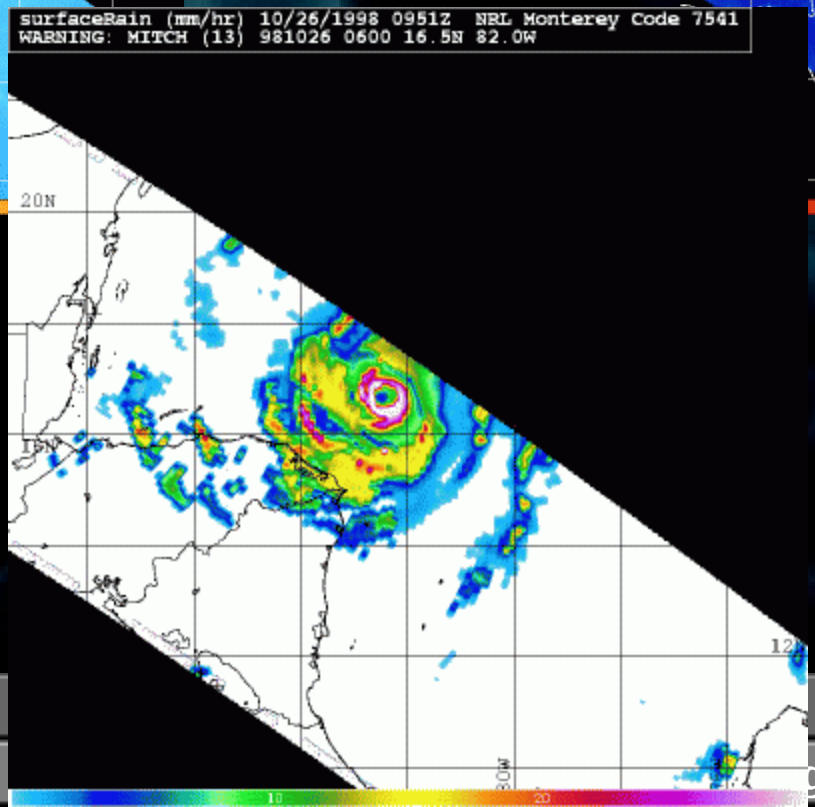
Surface Wind products



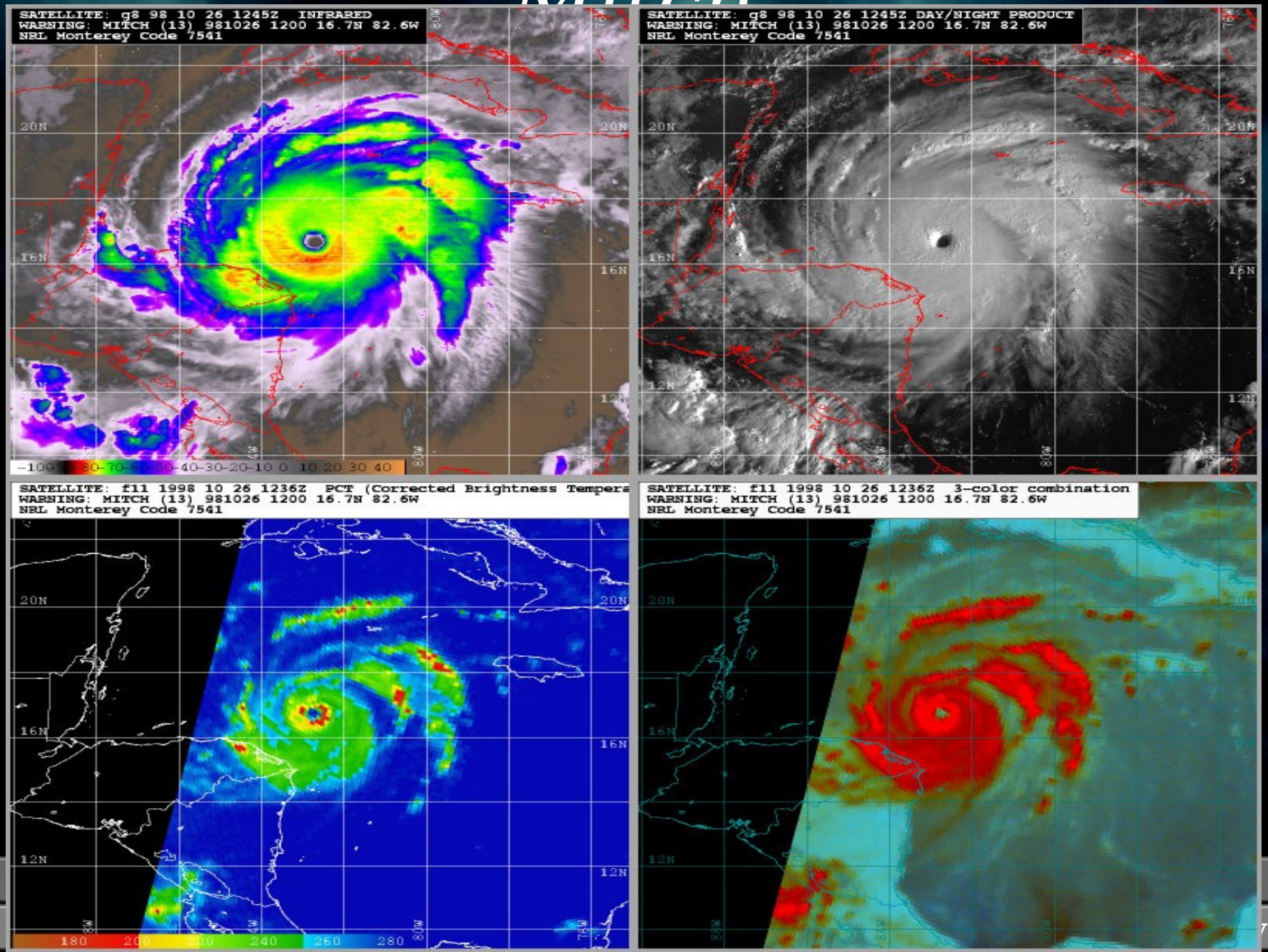
Series of Hurricane Mitch (3)



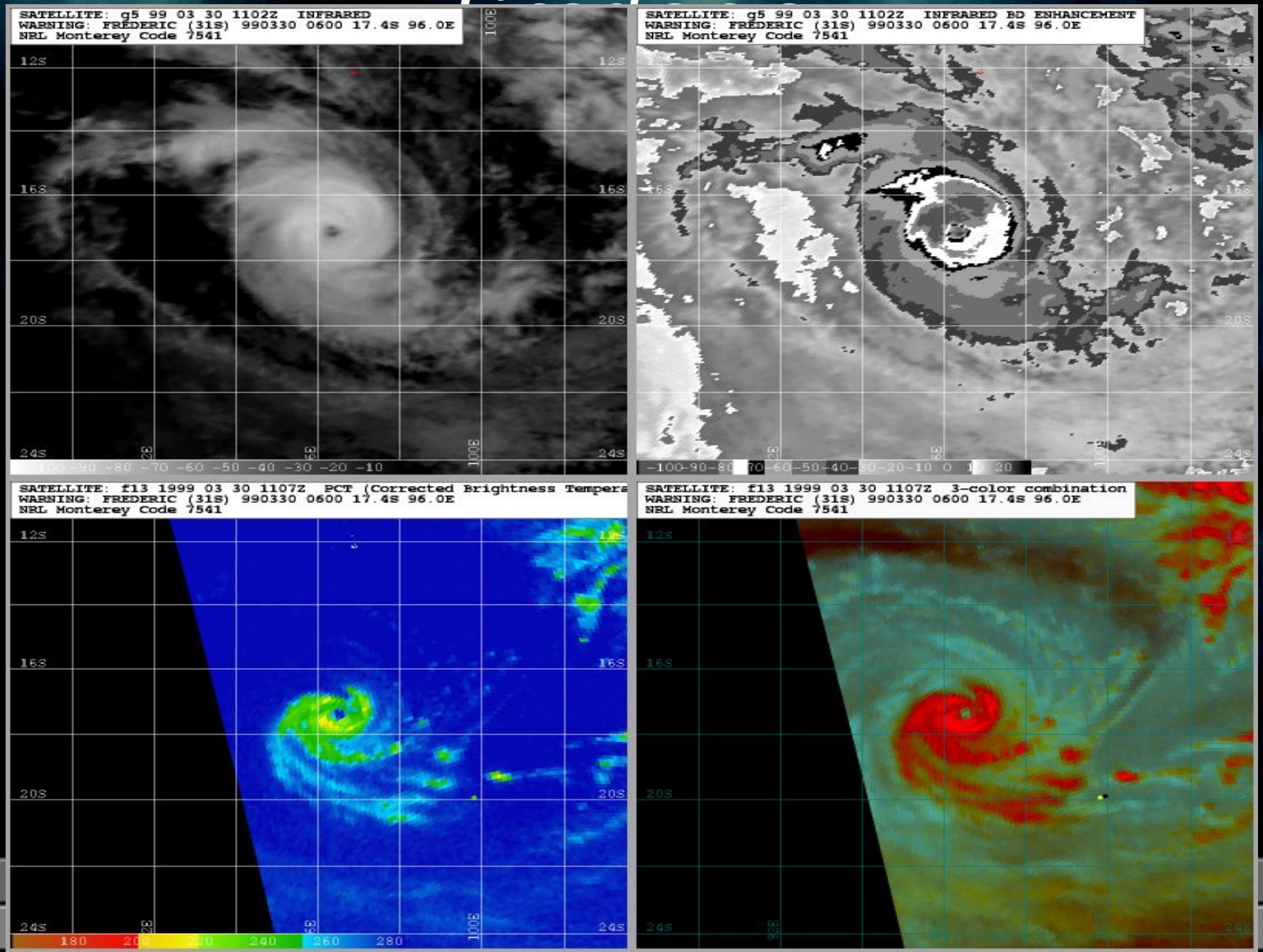




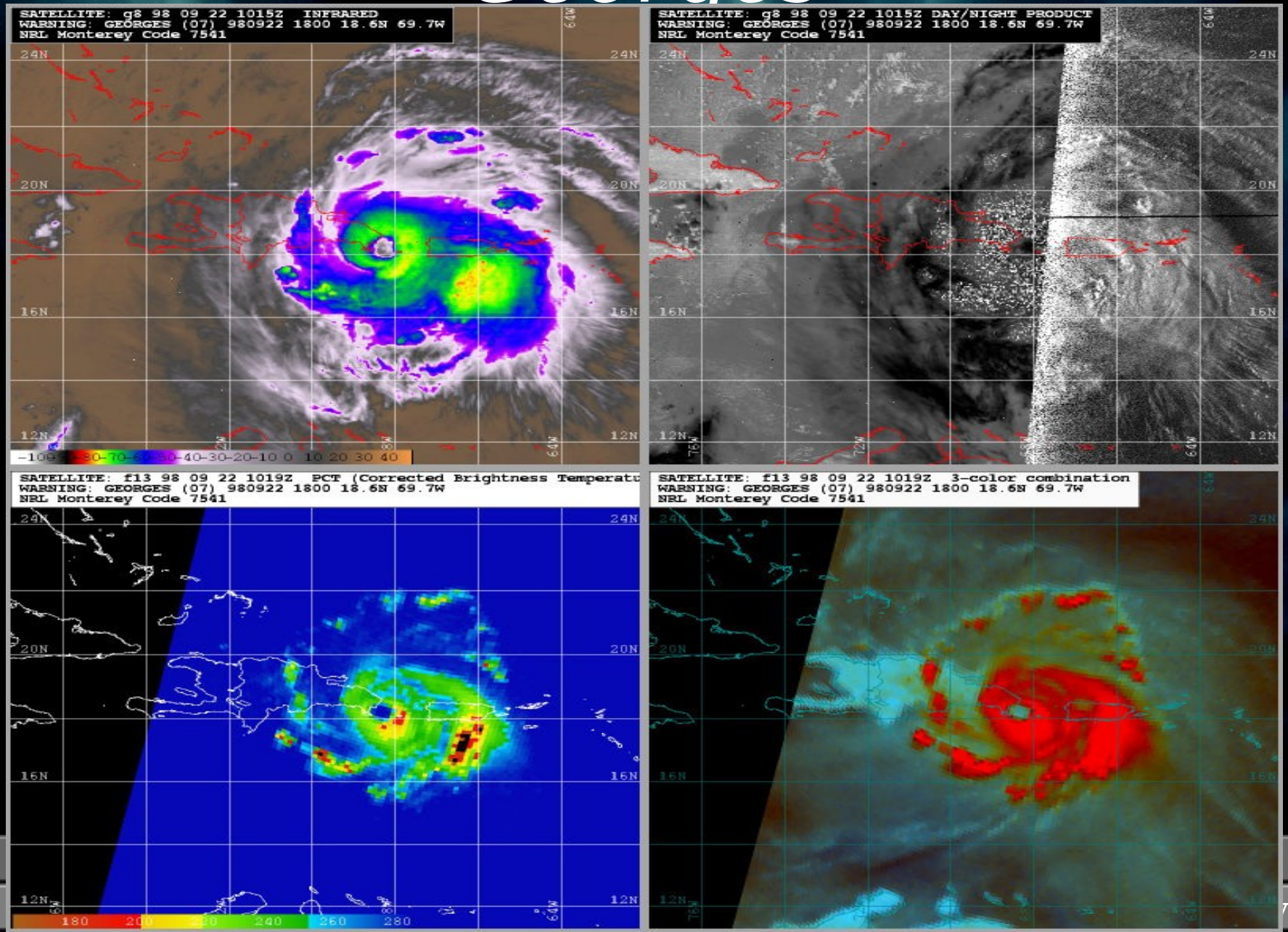
Composite of Hurricane Mitch


SATELLITE: g8 98 10 26 1245Z INFRARED
WARNING: MITCH (13) 981026 1200 16.7N 82.6W
NRL Monterey Code 7541
SATELLITE: g8 98 10 26 1245Z DAY/NIGHT PRODUCT
WARNING: MITCH (13) 981026 1200 16.7N 82.6W
NRL Monterey Code 7541
SATELLITE: f11 1998 10 26 1236Z PCT (Corrected Brightness Tempera
WARNING: MITCH (13) 981026 1200 16.7N 82.6W
NRL Monterey Code 7541
SATELLITE: f11 1998 10 26 1236Z 3-color combination
WARNING: MITCH (13) 981026 1200 16.7N 82.6W
NRL Monterey Code 7541
20N
16N
12N
80W

Composite of Cyclone Frederic


SATELLITE: g5 99 03 30 1102Z INFRARED
WARNING: FREDERIC (31S) 990330 0600 17.4S 96.0E
NRL Monterey Code 7541
SATELLITE: g5 99 03 30 1102Z INFRARED BD ENHANCEMENT
WARNING: FREDERIC (31S) 990330 0600 17.4S 96.0E
NRL Monterey Code 7541
SATELLITE: f13 1999 03 30 1107Z PCT (Corrected Brightness Tempera
WARNING: FREDERIC (31S) 990330 0600 17.4S 96.0E
NRL Monterey Code 7541
SATELLITE: f13 1999 03 30 1107Z 3-color combination
WARNING: FREDERIC (31S) 990330 0600 17.4S 96.0E
NRL Monterey Code 7541

Composite of Hurricane Georges


SATELLITE: g8 98 09 22 1015Z INFRARED
WARNING: GEORGES (07) 980922 1800 18.6N 69.7W
NRL Monterey Code 7541
SATELLITE: g8 98 09 22 1015Z DAY/NIGHT PRODUCT
WARNING: GEORGES (07) 980922 1800 18.6N 69.7W
NRL Monterey Code 7541
SATELLITE: f13 98 09 22 1019Z PCT (Corrected Brightness Temperatu
WARNING: GEORGES (07) 980922 1800 18.6N 69.7W
NRL Monterey Code 7541
SATELLITE: f13 98 09 22 1019Z 3-color combination
WARNING: GEORGES (07) 980922 1800 18.6N 69.7W
NRL Monterey Code 7541
24N
20N
16N
12N
180 200 220 240 260 280

Review

- Microwave imagery
  - Microwave theory
  - Microwave radiance variables
  - Raw data applications
  - Derived products

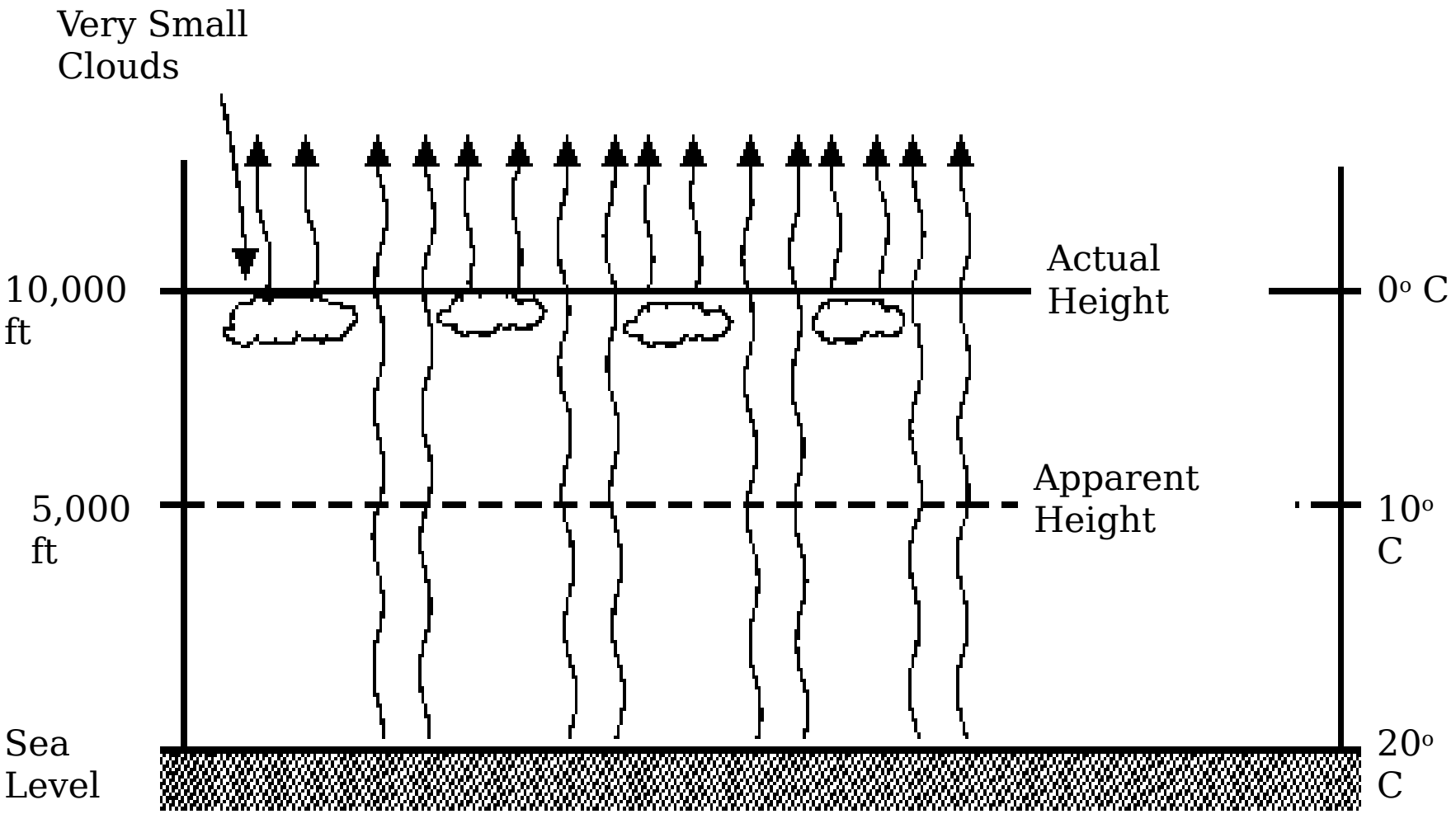
Satellite Imagery Viewing Considerations

- Resolution
  - The smallest individual element that a satellite sensor can detect. This is designated on the imagery as one pixel
  - The best resolution is always directly beneath the satellite where the distance between the satellite and the surface is the shortest. This is known as the subpoint
  - For polar orbiting satellites, its called the subtrack. The further an object is from the subpoint, the poorer the resolution becomes

Resolution

- Finer (greater or higher) resolution allows smaller individual elements to be seen
  - If objects are smaller than resolution of sensor
    - Individual elements will not be seen
    - Gray shades averaged
  - If objects are larger than resolution of sensor object will be displayed normally
- Lower resolution images do not allow small elements to be seen resulting in less detailed image

Resolution

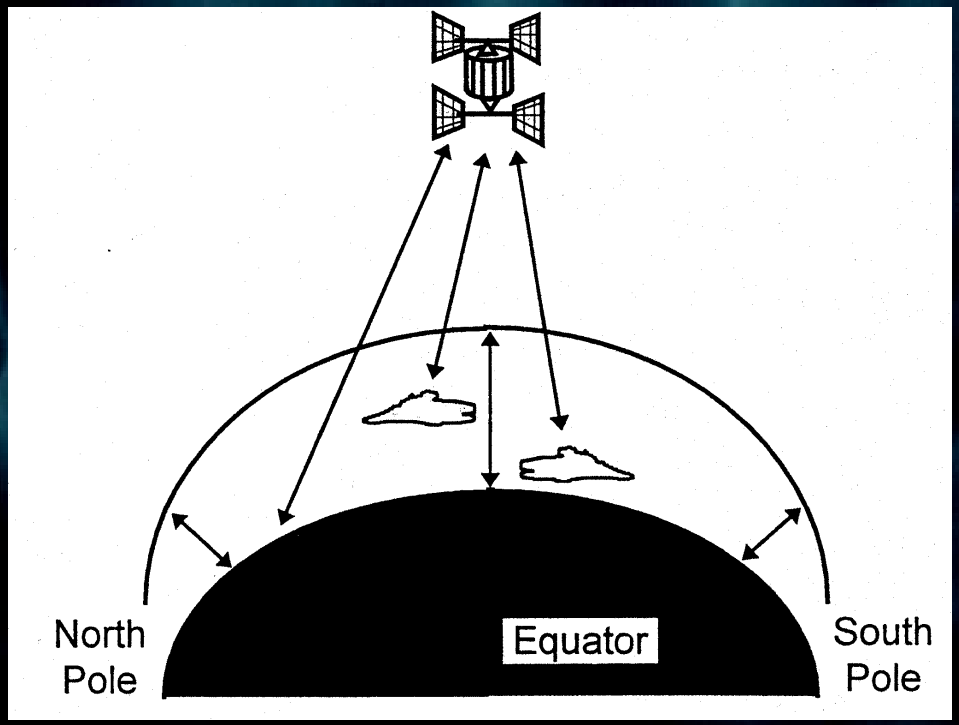

Very Small Clouds
10,000 ft
5,000 ft
Sea Level
Actual Height
Apparent Height
0° C
10° C
20° C

Satellite Imagery Viewing Considerations

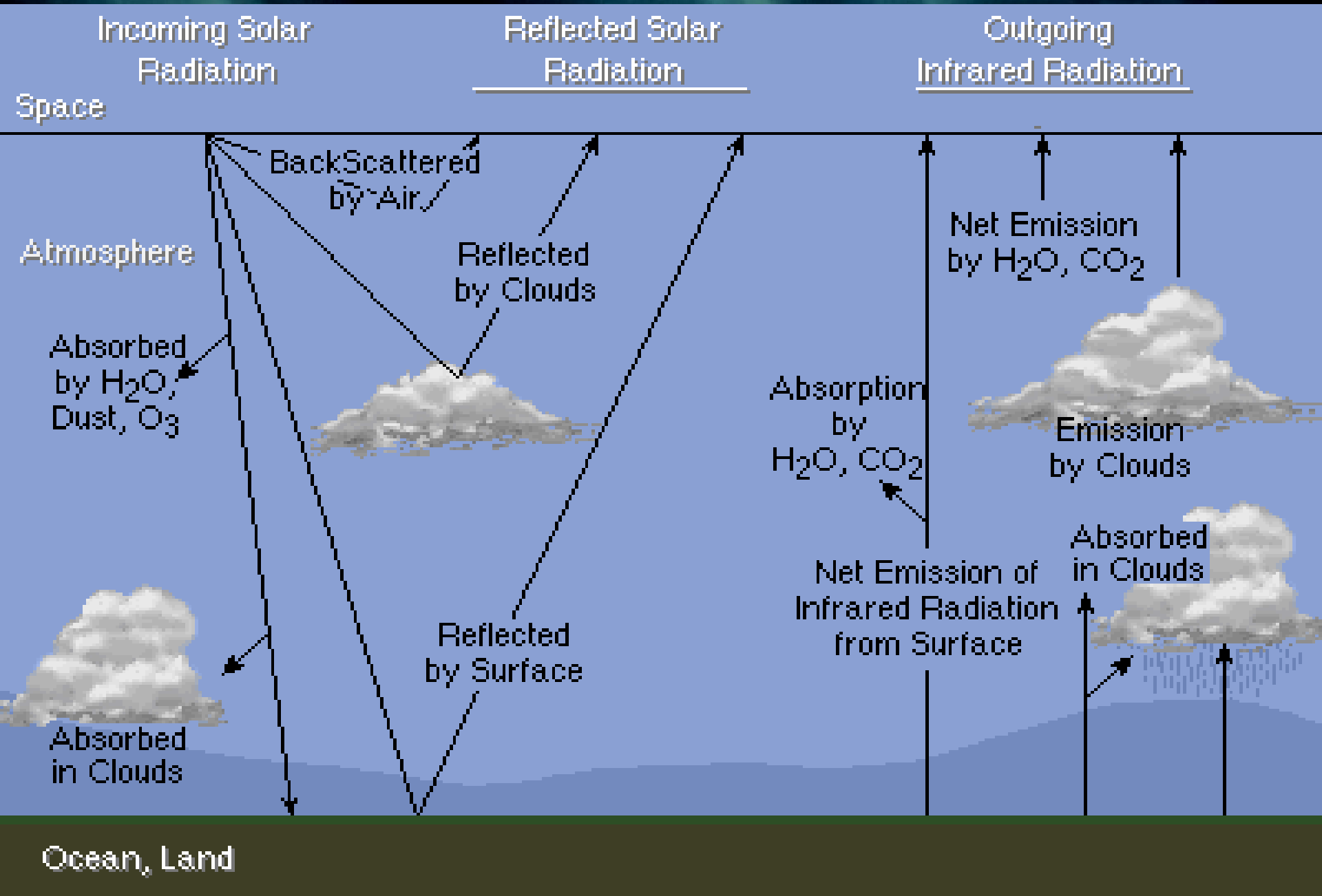
- Attenuation
  - Loss of energy (EMR) due to atmospheric absorption and scattering
  - Affects Infrared and Water Vapor imagery by reducing the amount of energy reaching the satellite sensor
  - Clouds appear colder (higher)

Viewing Considerations
Attenuation

- Amount of attenuation depends on three things:
  - –Viewing angle of the satellite
  - –Depth of the atmosphere
  - –Height of the clouds



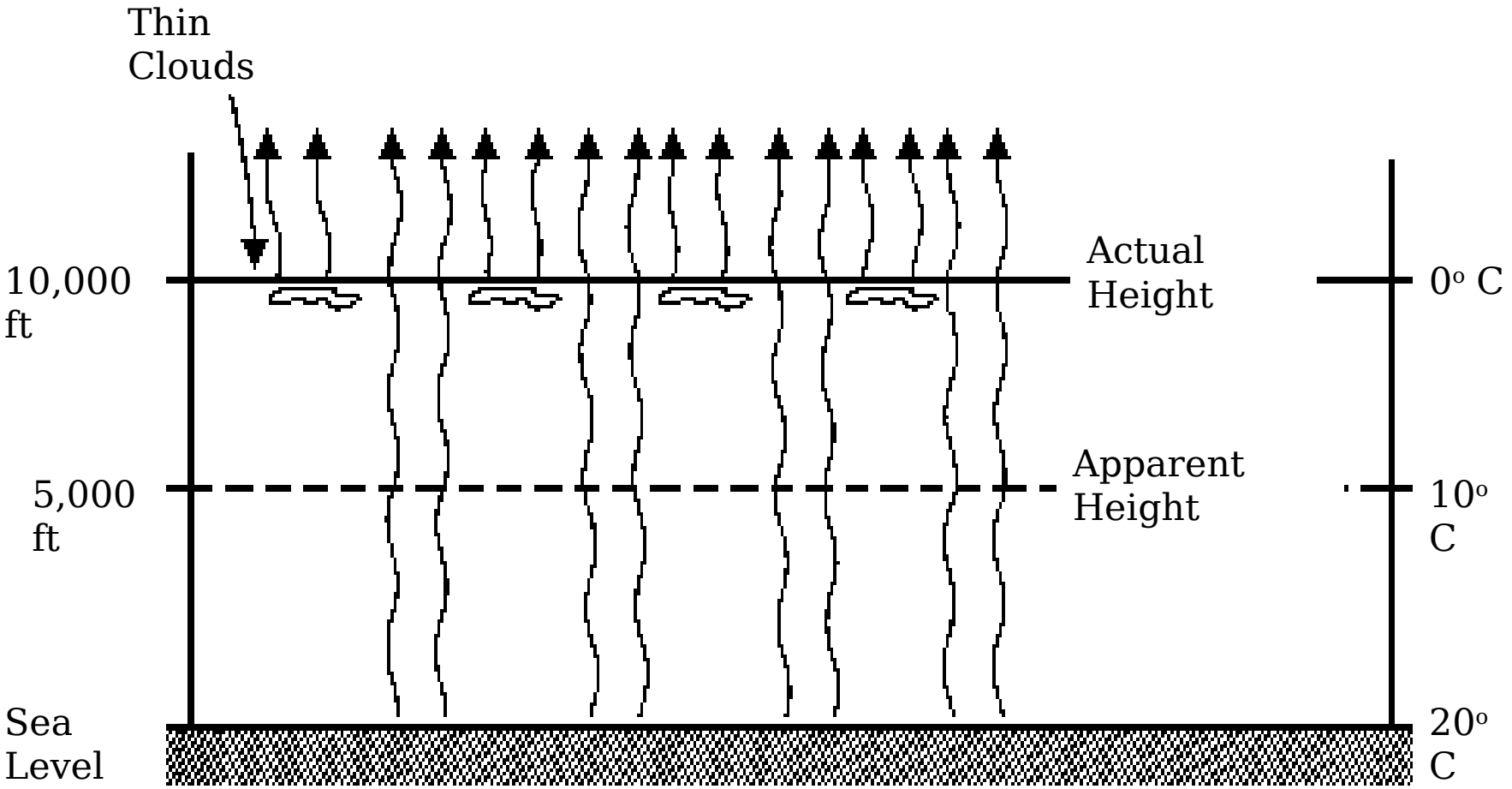
Attenuation



Satellite Imagery Viewing Considerations

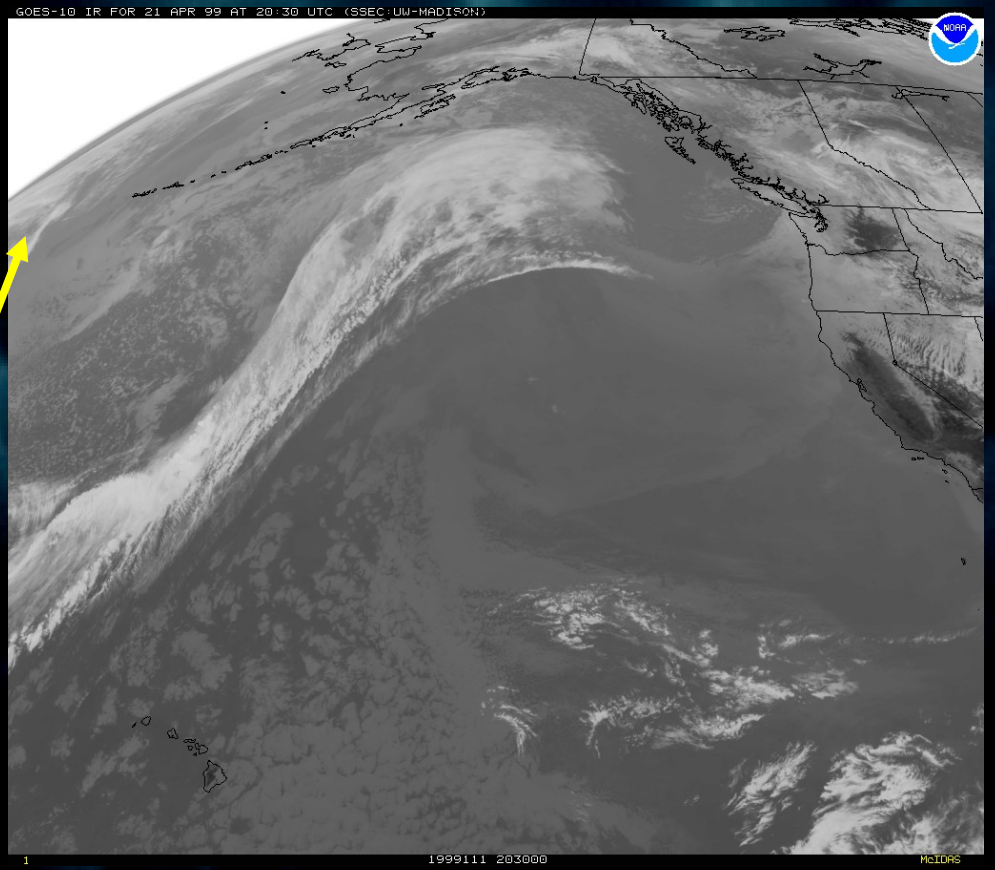
- Contamination
  - Energy reaches the satellite sensor from two or more sources
  - Occurs on both infrared and visible images
    - Infrared imagery contamination causes clouds to appear lower and warmer
    - Visible imagery contamination occurs when thin high clouds partially obscure clouds below
    - Occurs when cloud elements are smaller than the sensor's resolution

Contamination

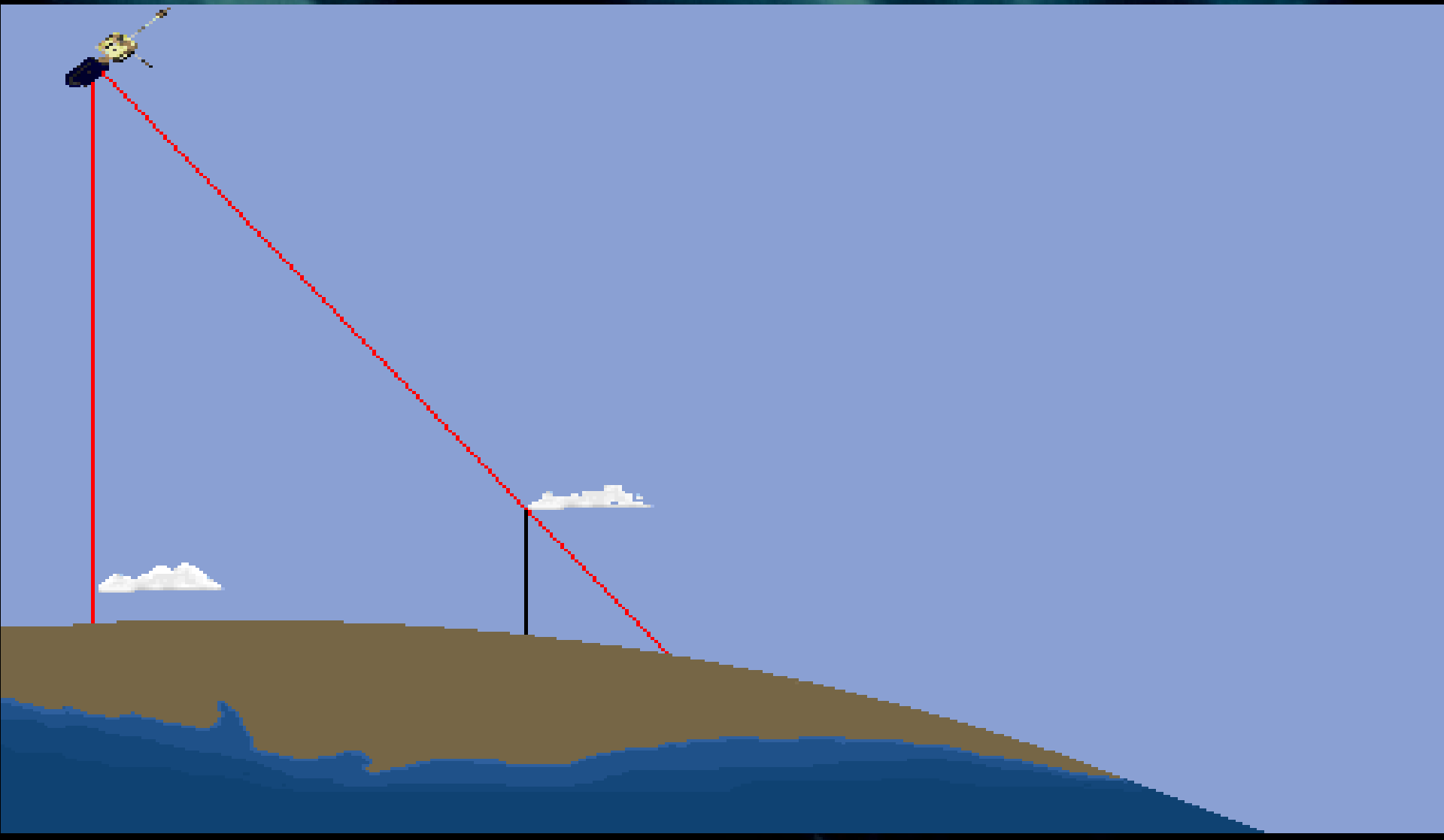


Satellite Imagery Viewing Considerations

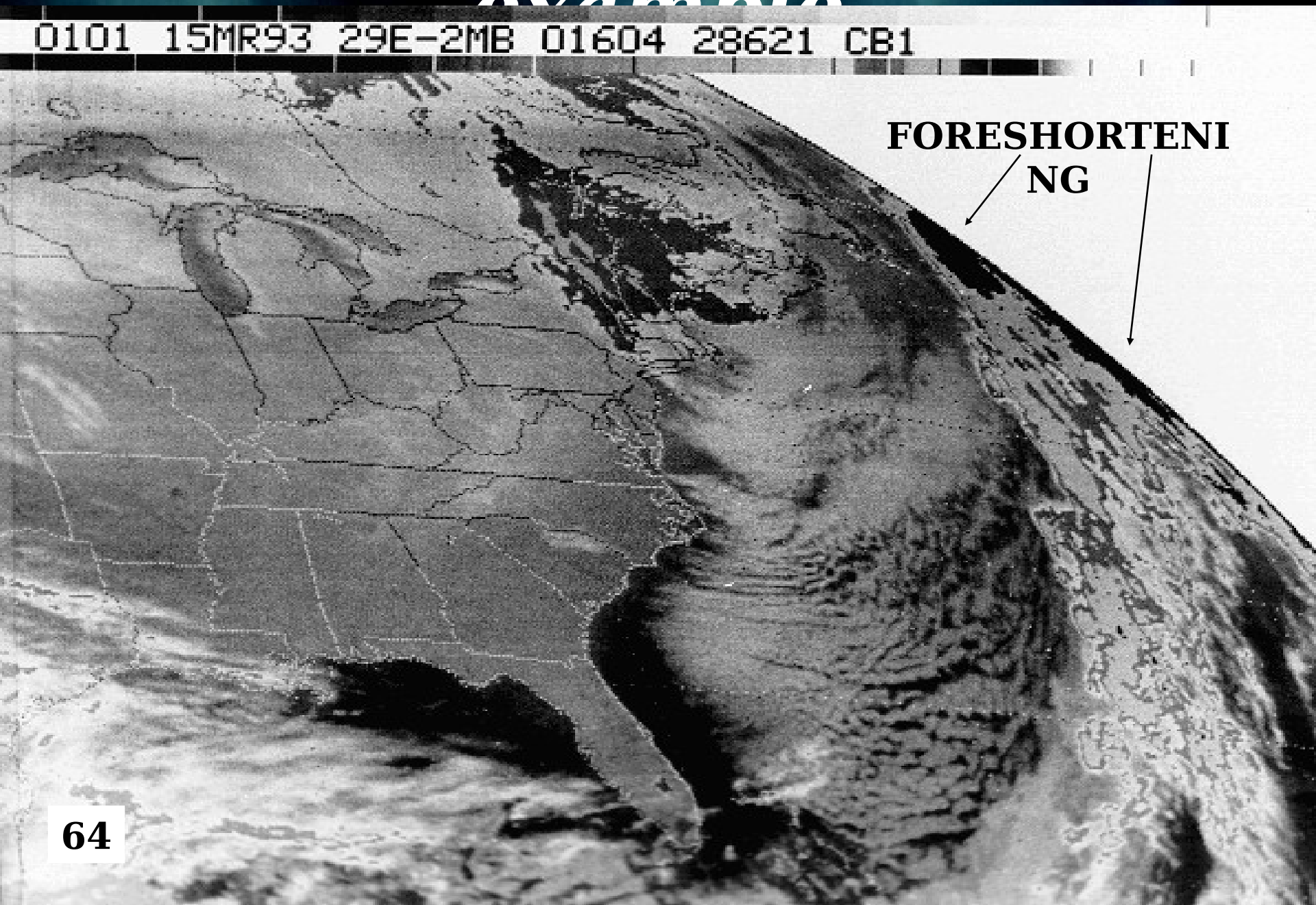
- Foreshortening
  - Loss of resolution caused by an oblique viewing angle
  - Occurs near the edge of any image
  - Results in overestimation of cloud coverage



Foreshortening



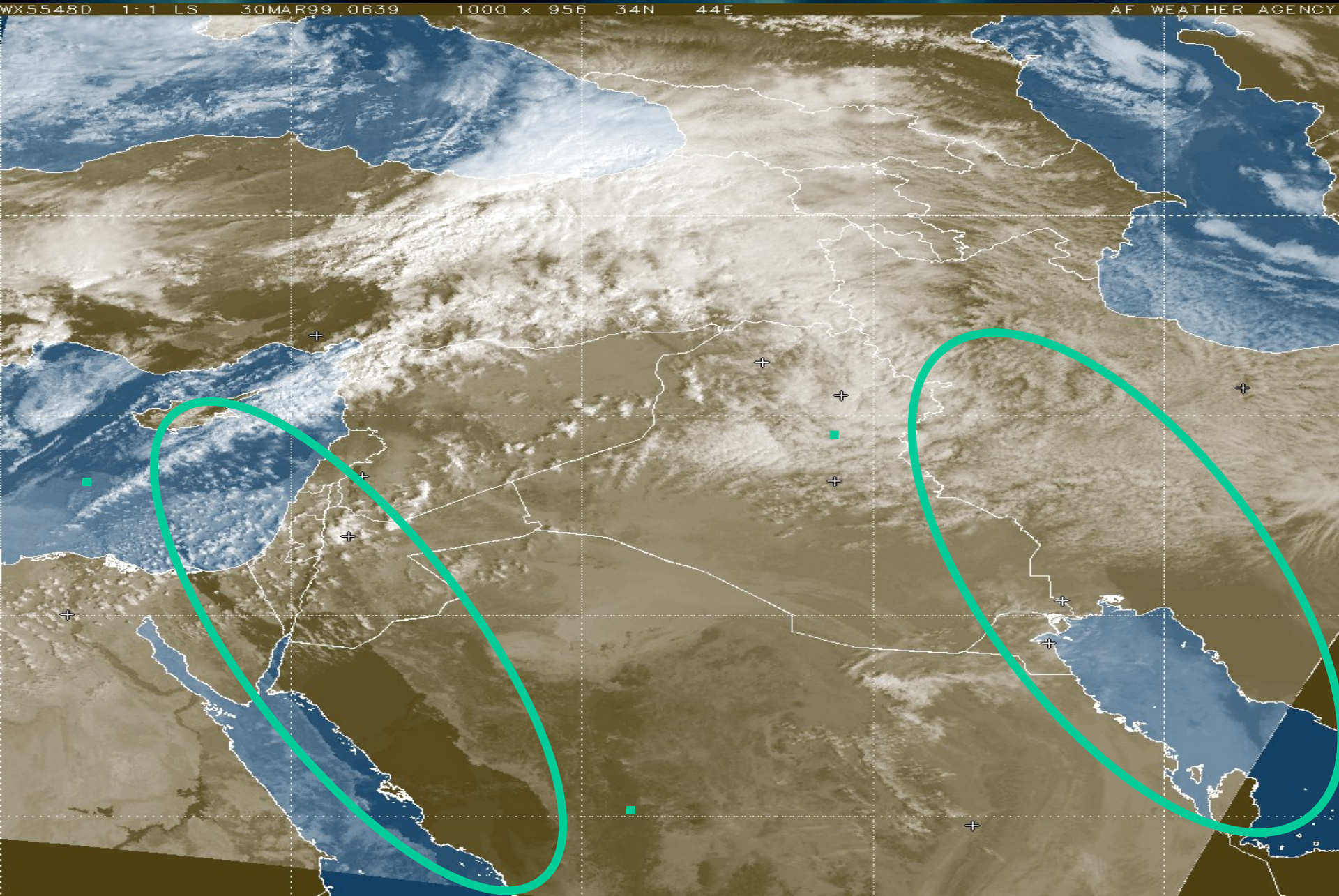
Foreshortening example



Satellite Imagery Viewing Considerations

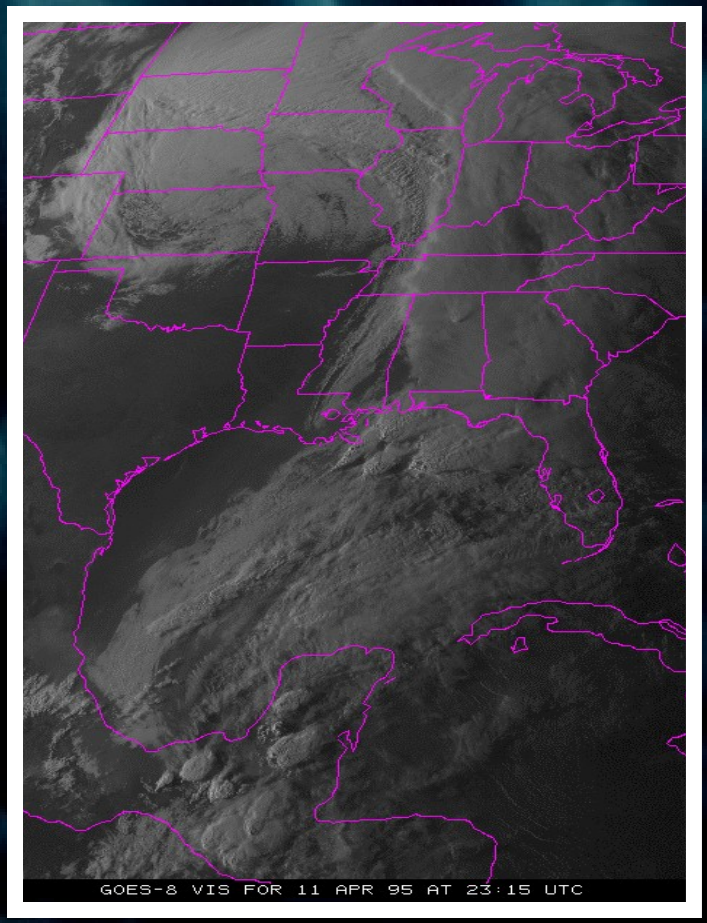
- Gridding errors
  - Occasionally, gridding errors occur when the geographic grid is misaligned on the image
  - However, with today's advanced satellite software you will be able to adjust and/or customize your geographic grids

Gridding Errors

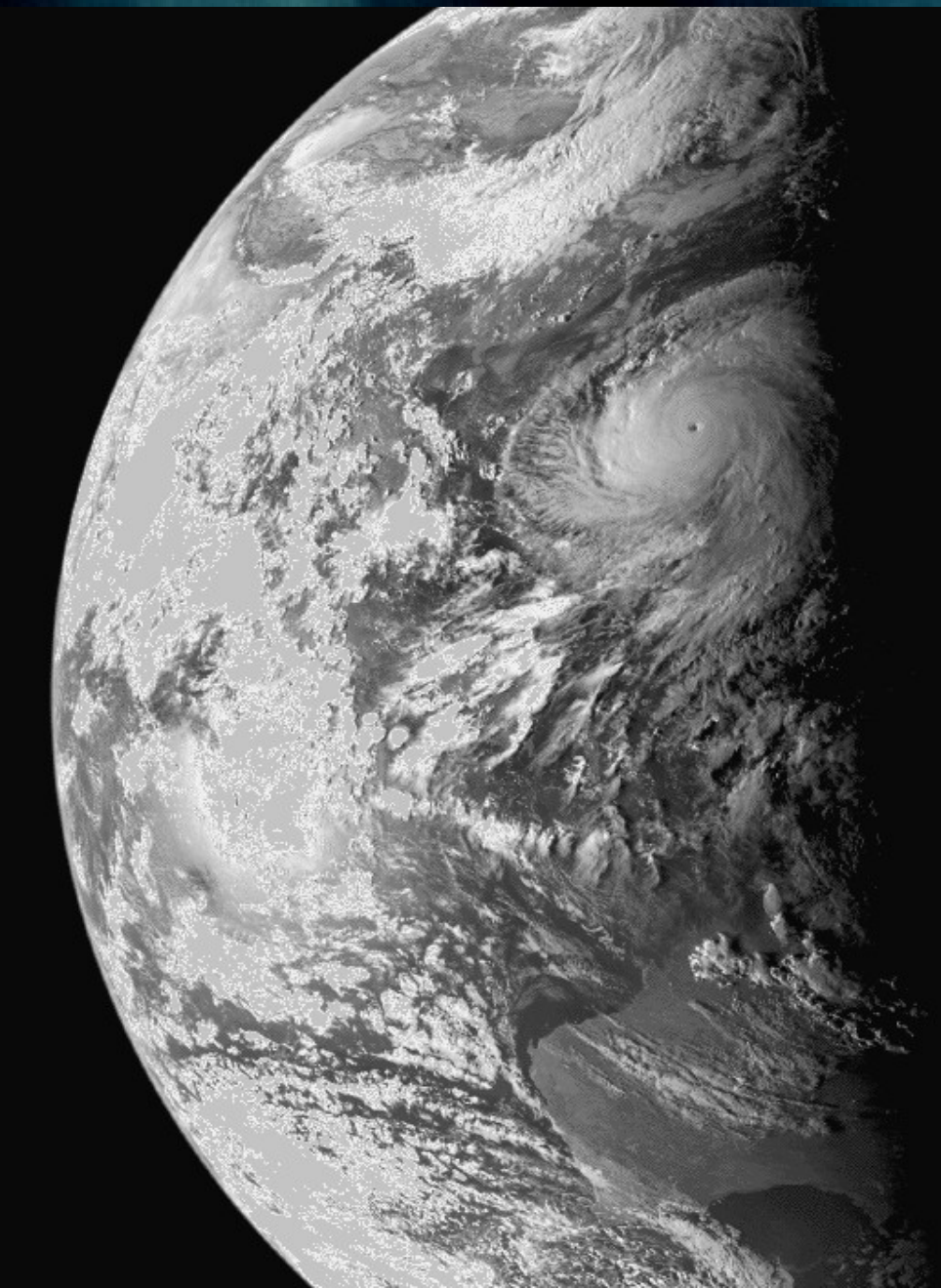


Satellite Imagery Viewing Considerations

- Sun angle
  - "The Terminator"
  - Enhances cloud texture by showing shadows
  - Shadows occur during early morning and late evening



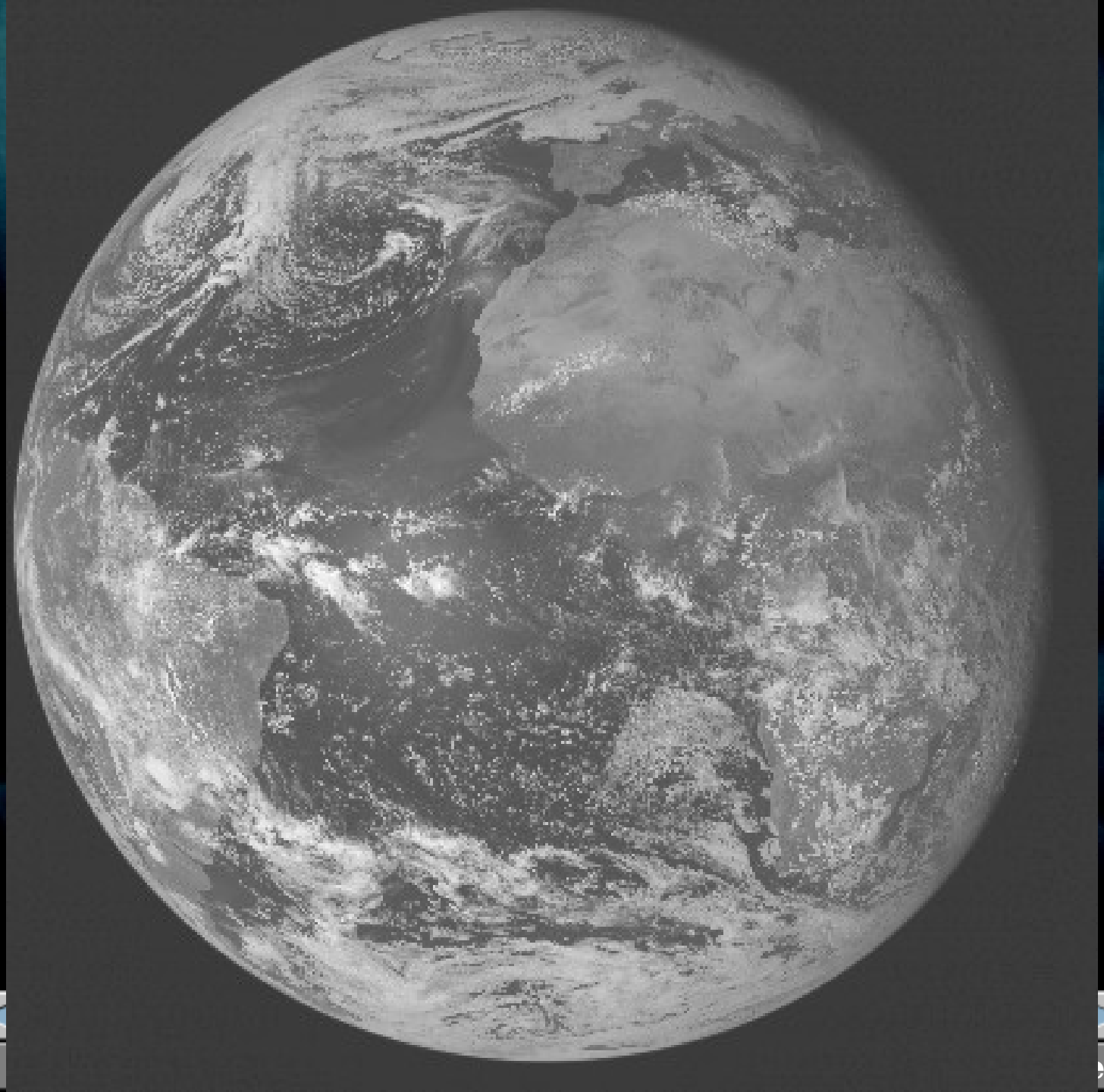
Sun Angle



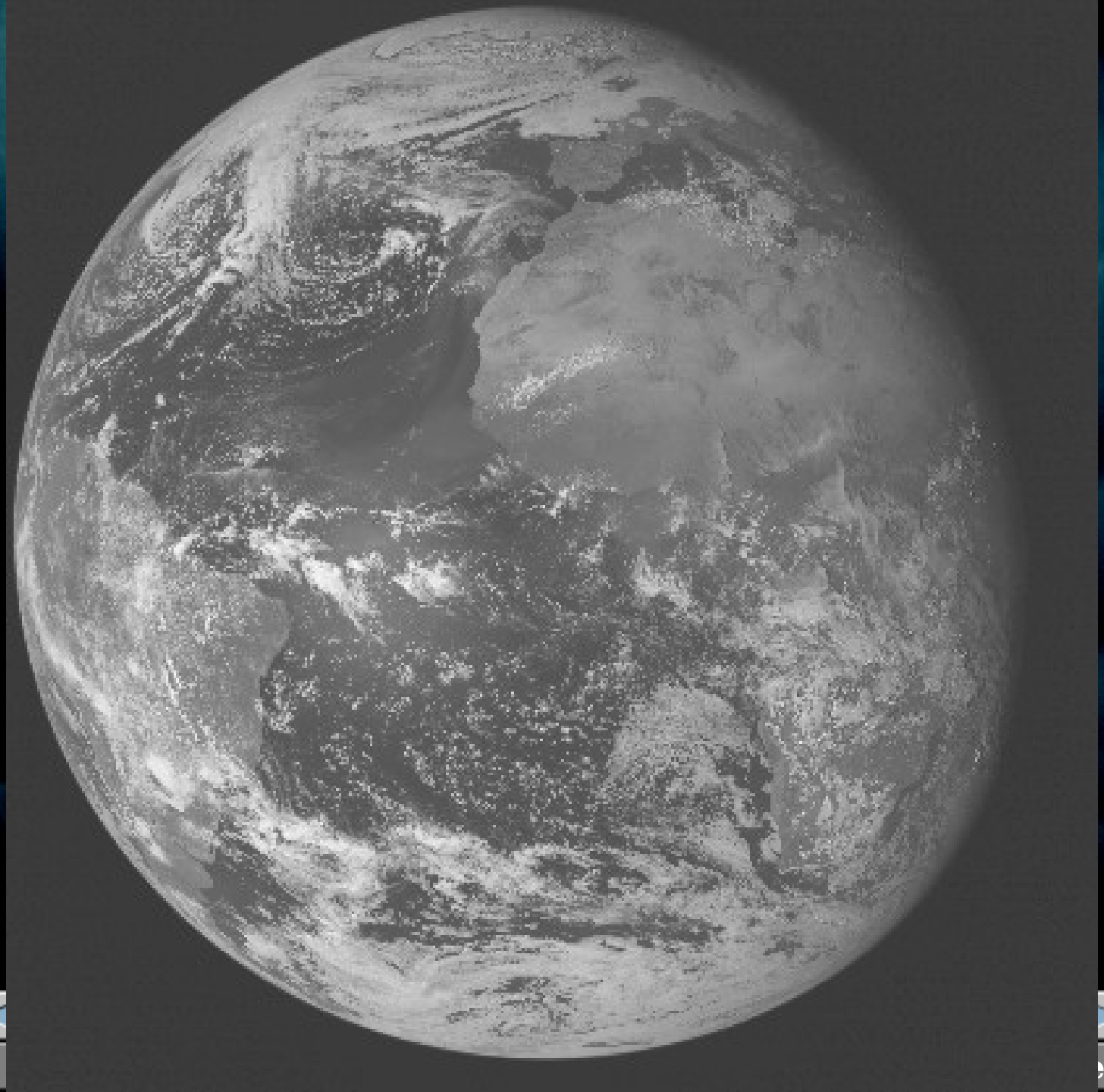
Typhoon Zeb, 180 mph sustained winds, GMS vis image, 13 Oct 98

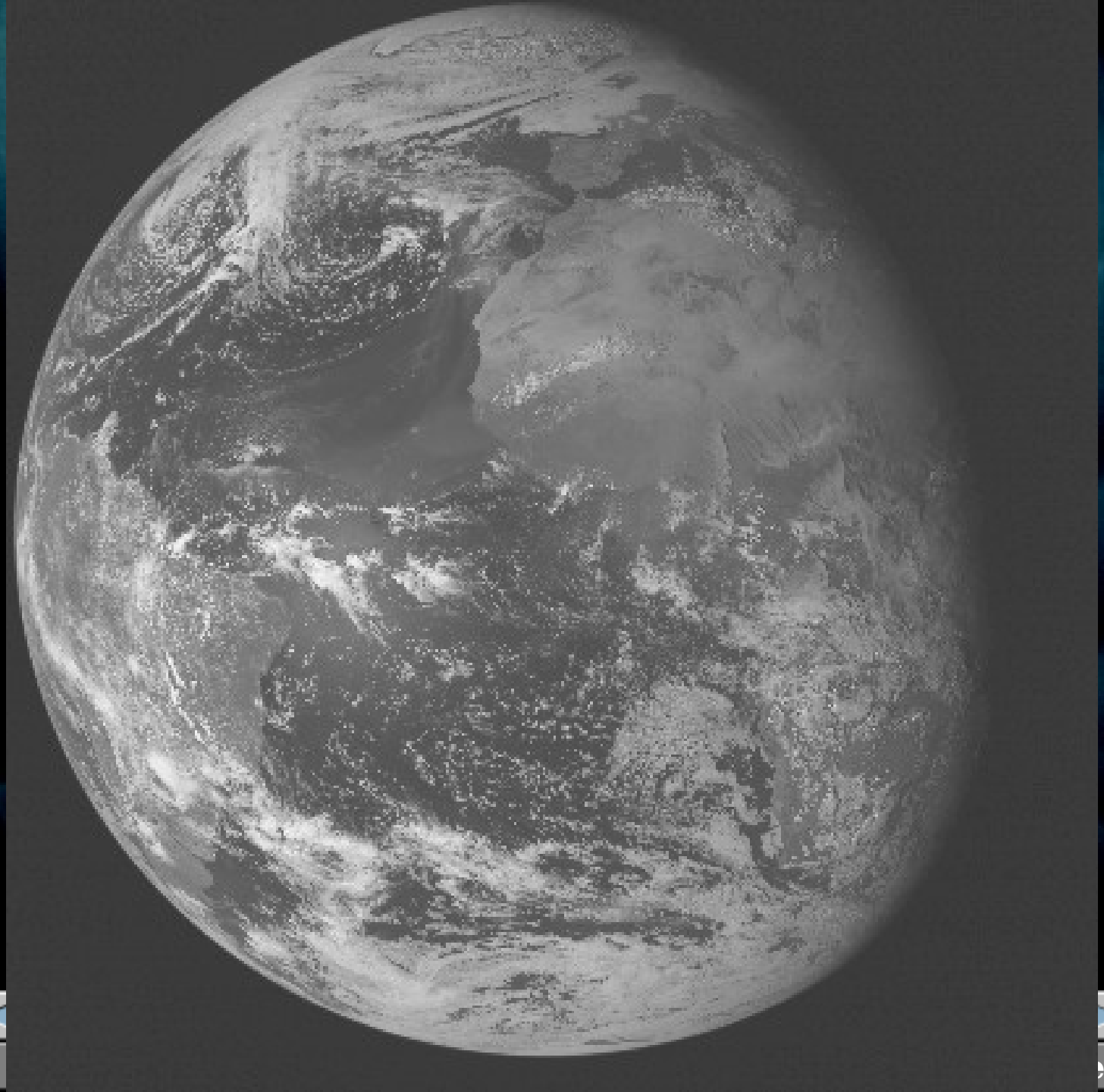
“ The Terminator”

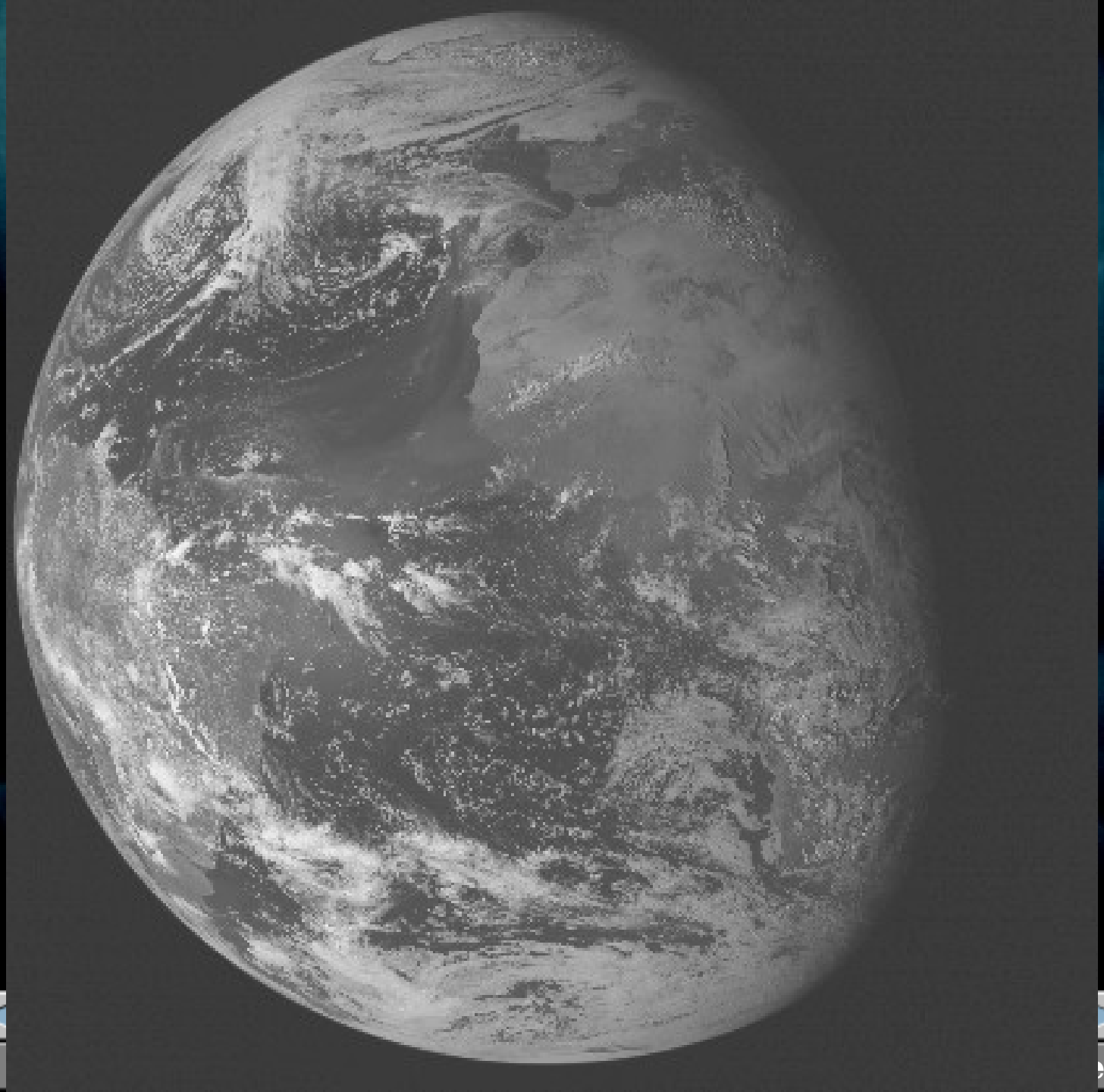
Eclipse

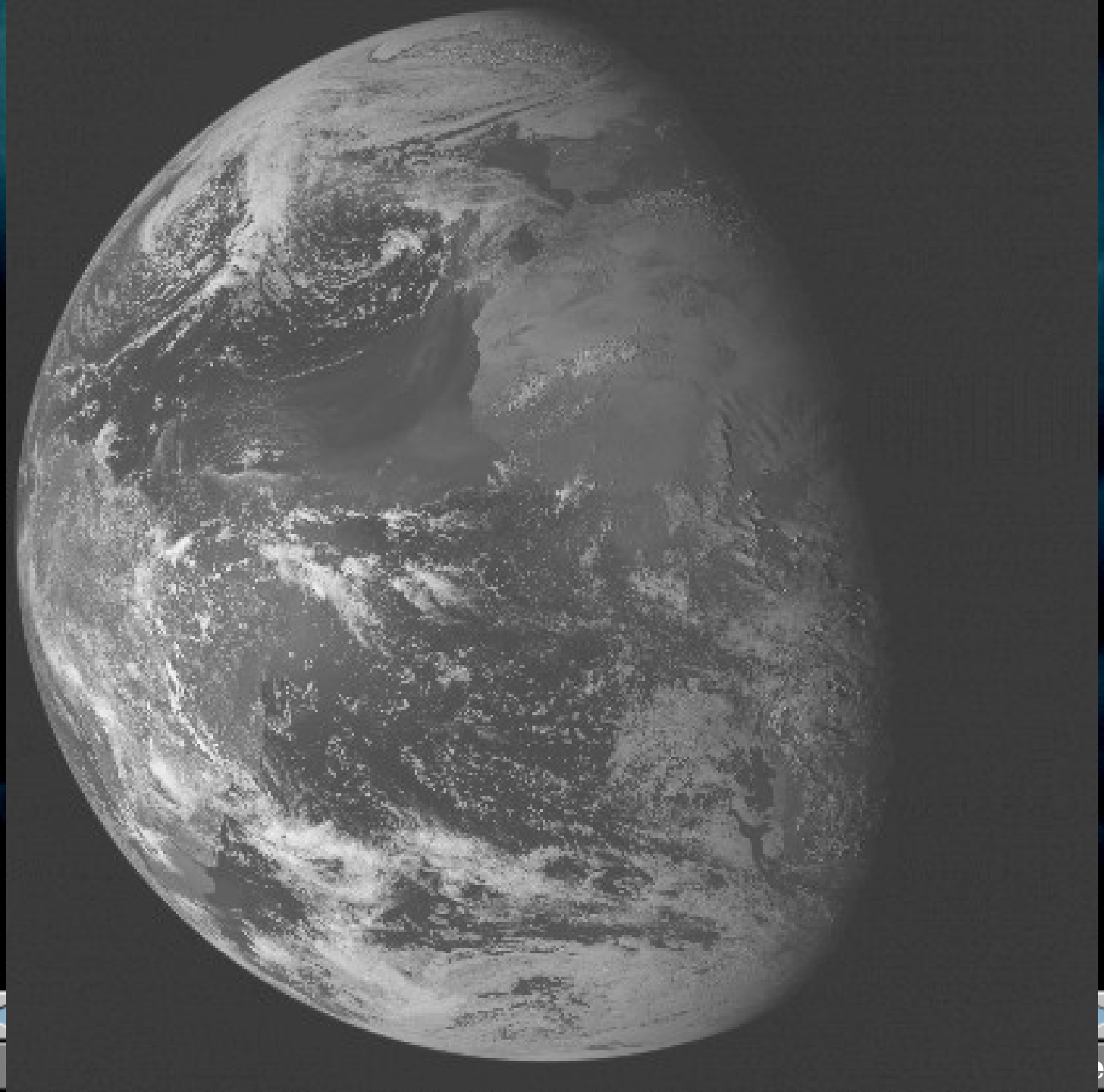


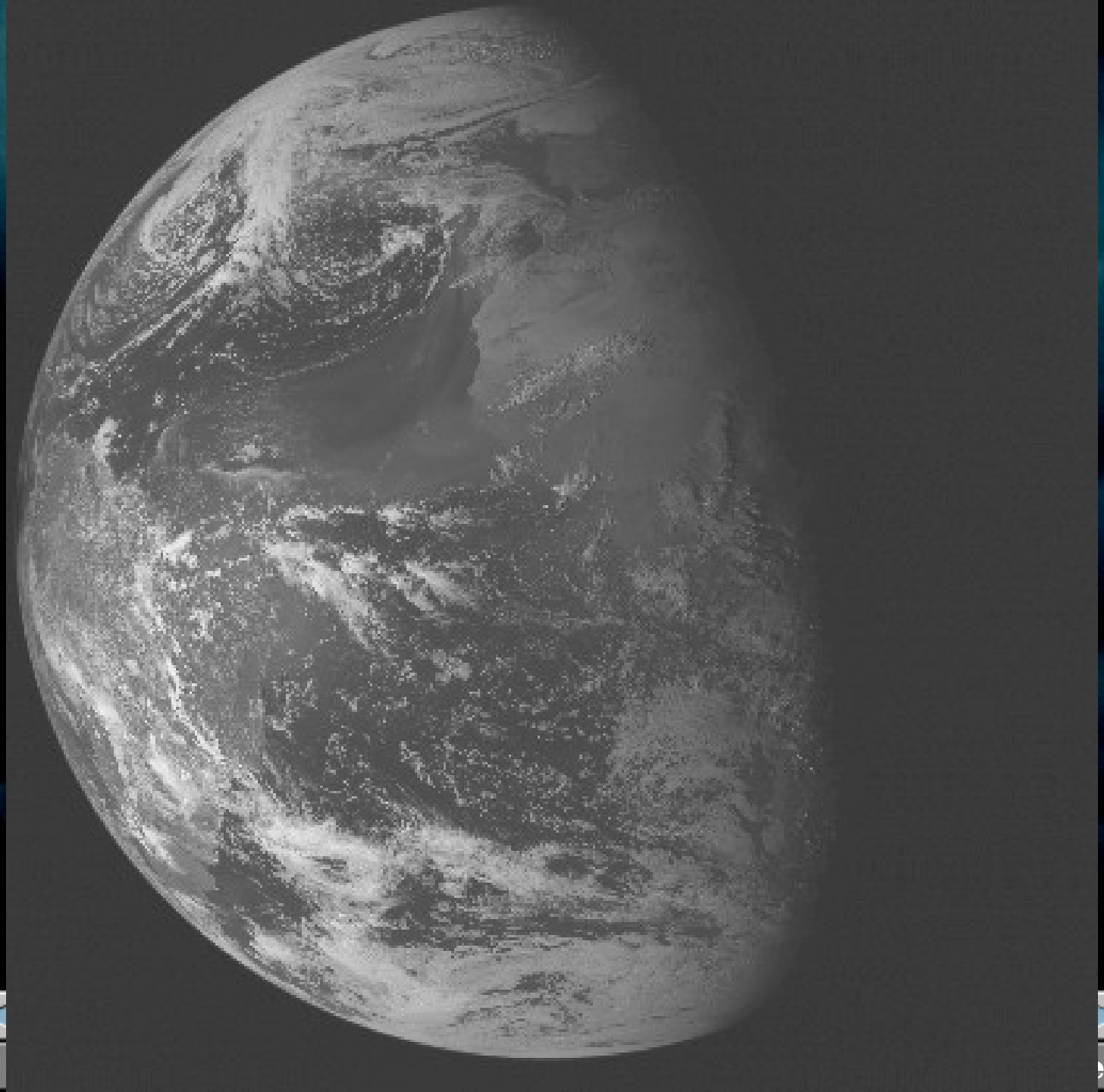
ebruary 20

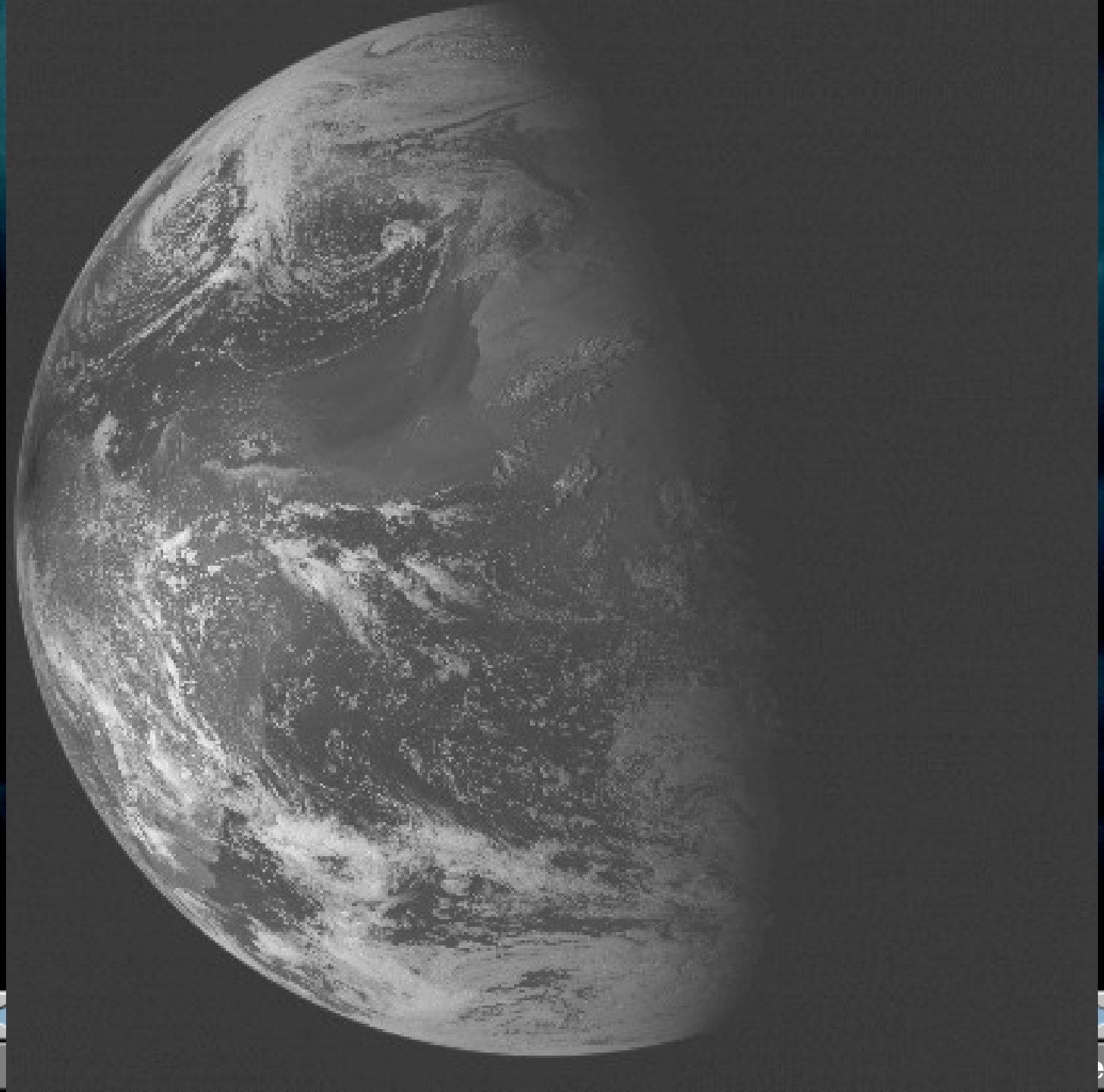


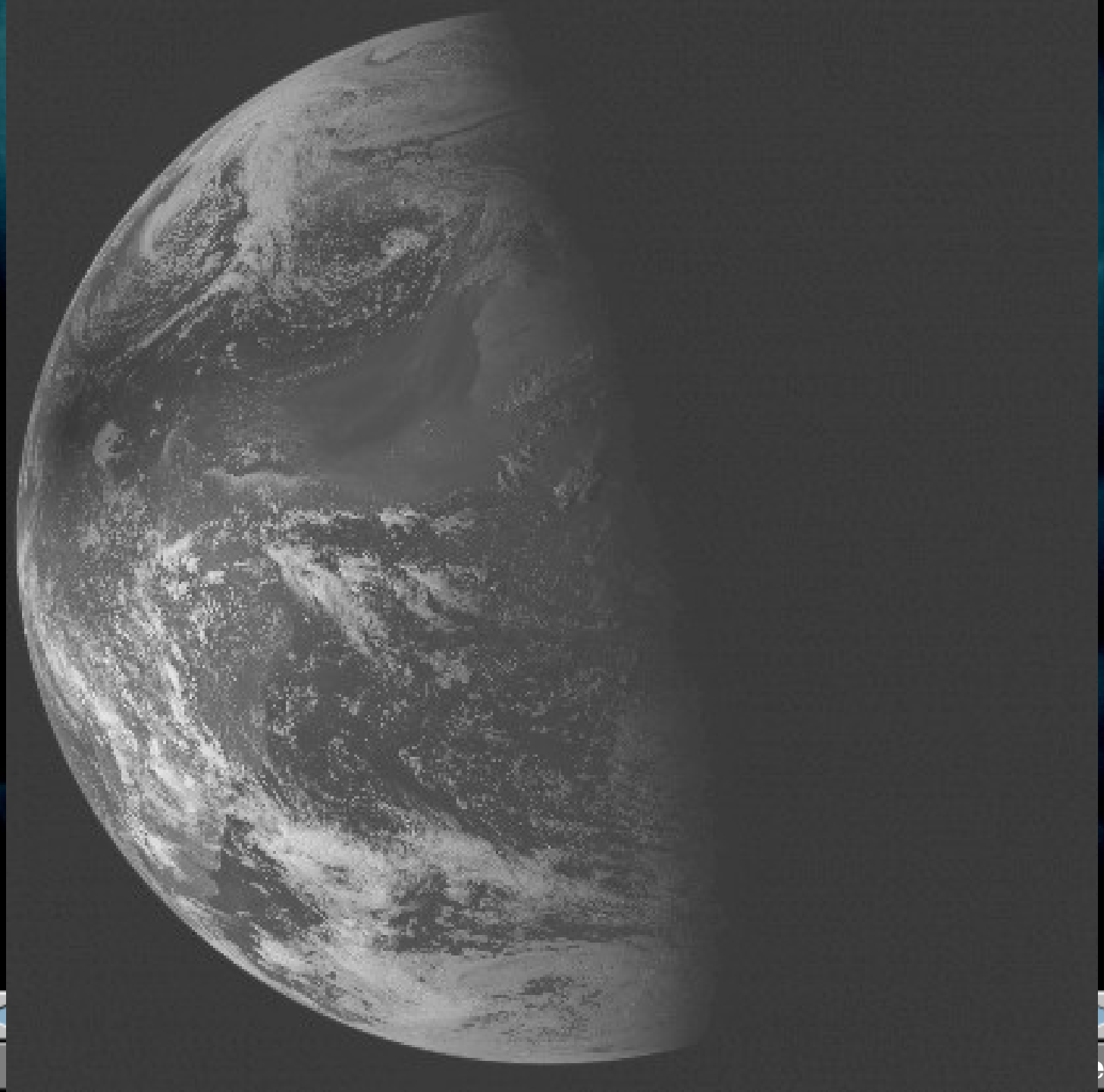


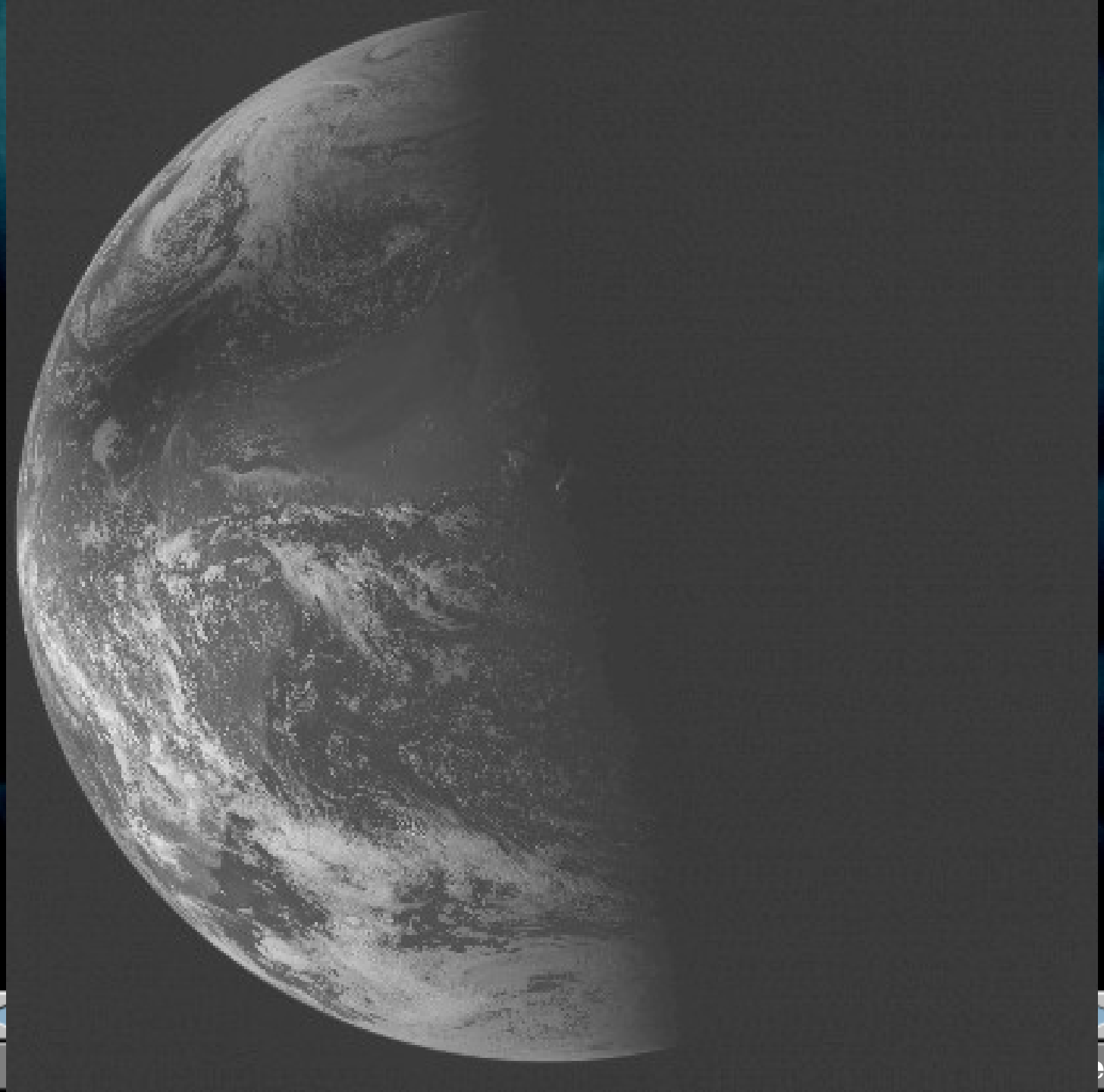


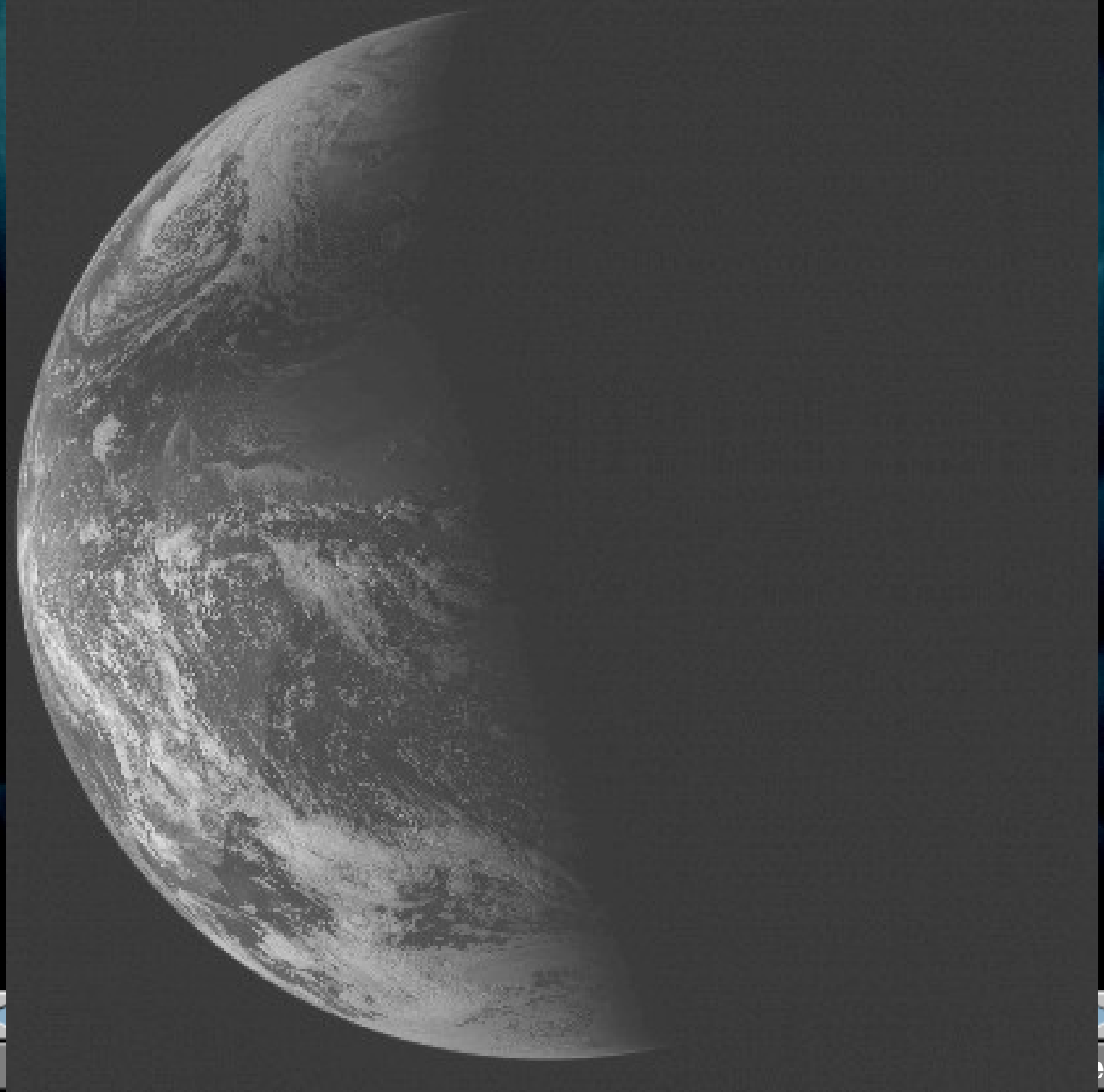


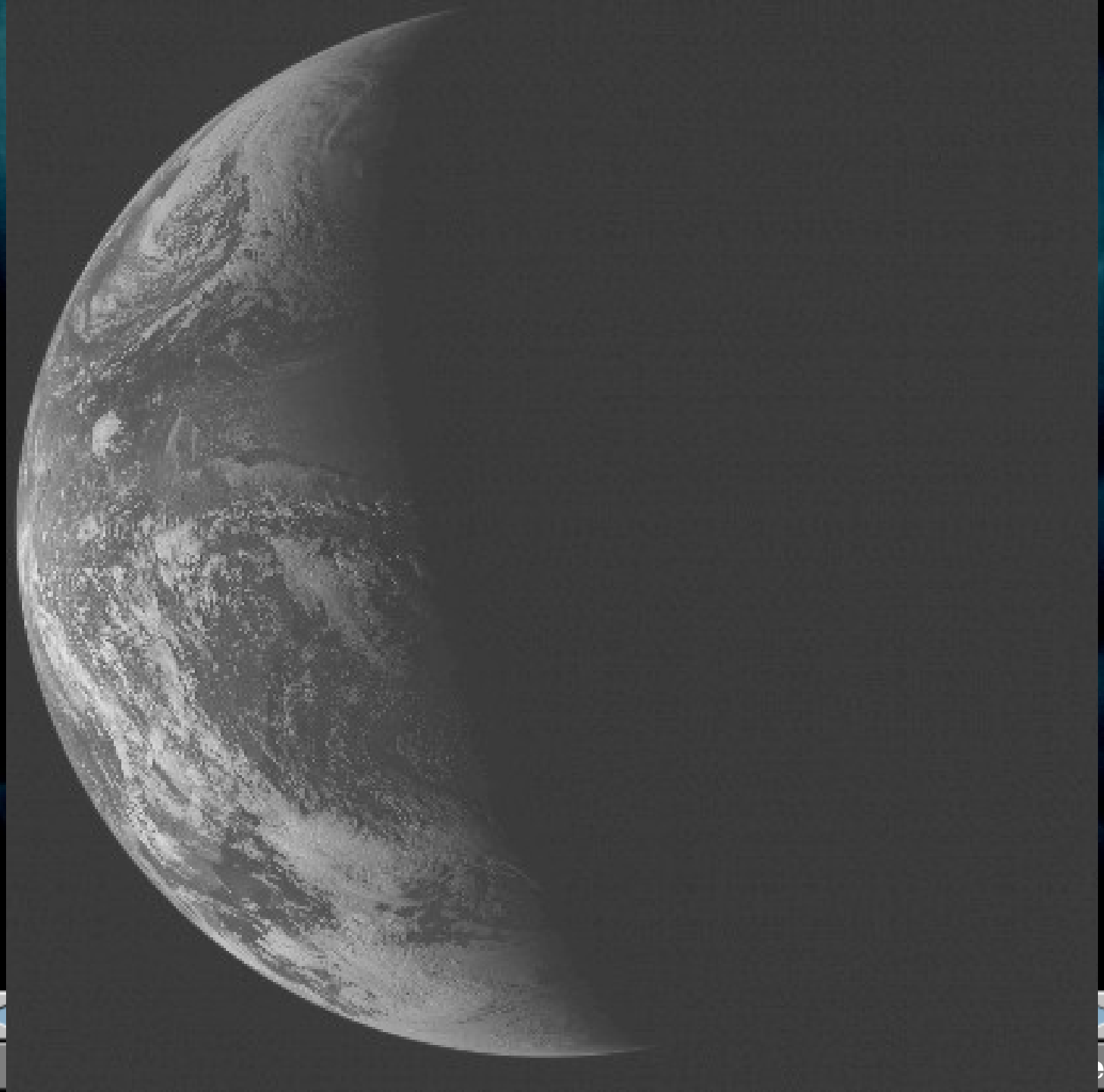


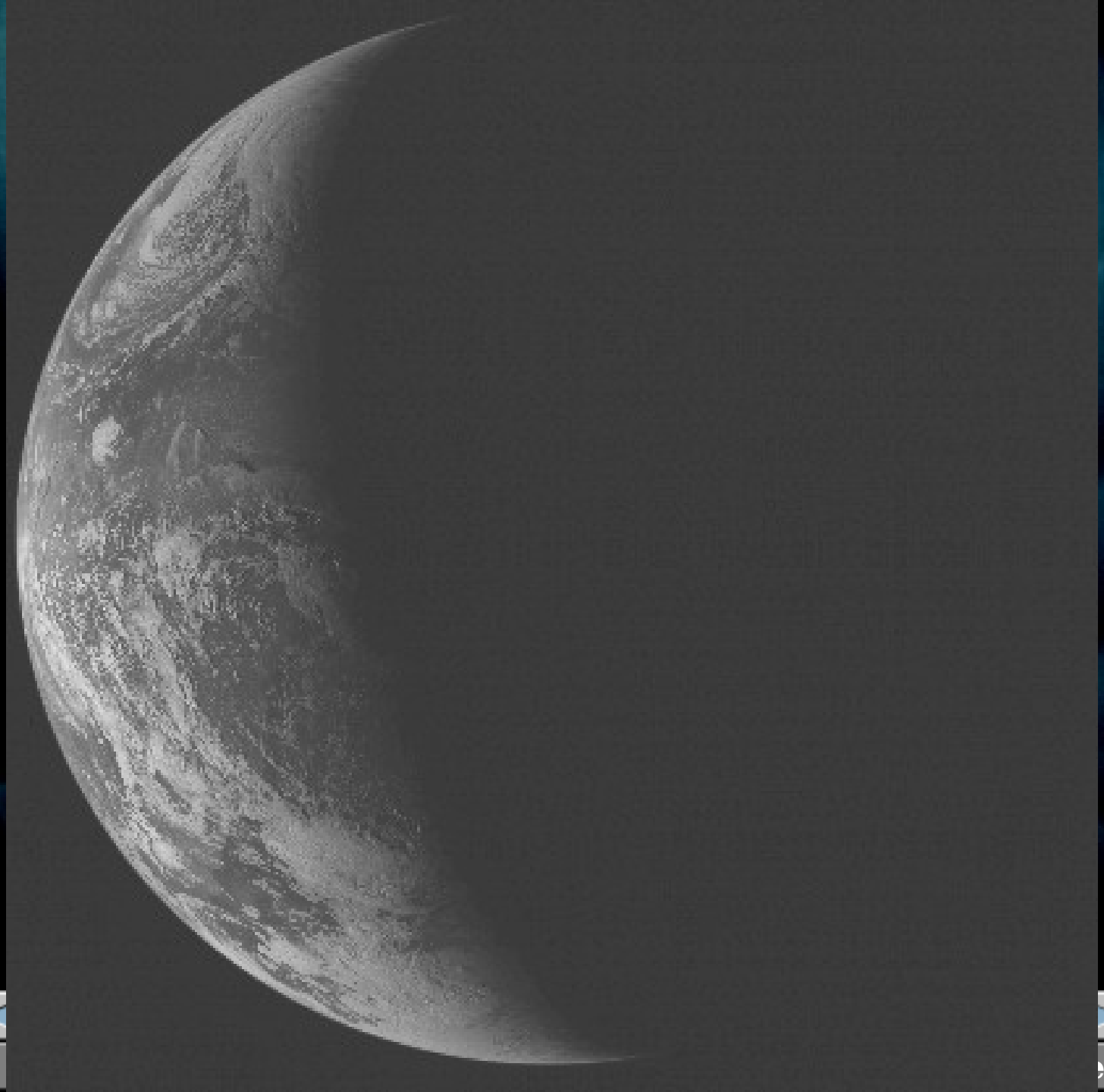


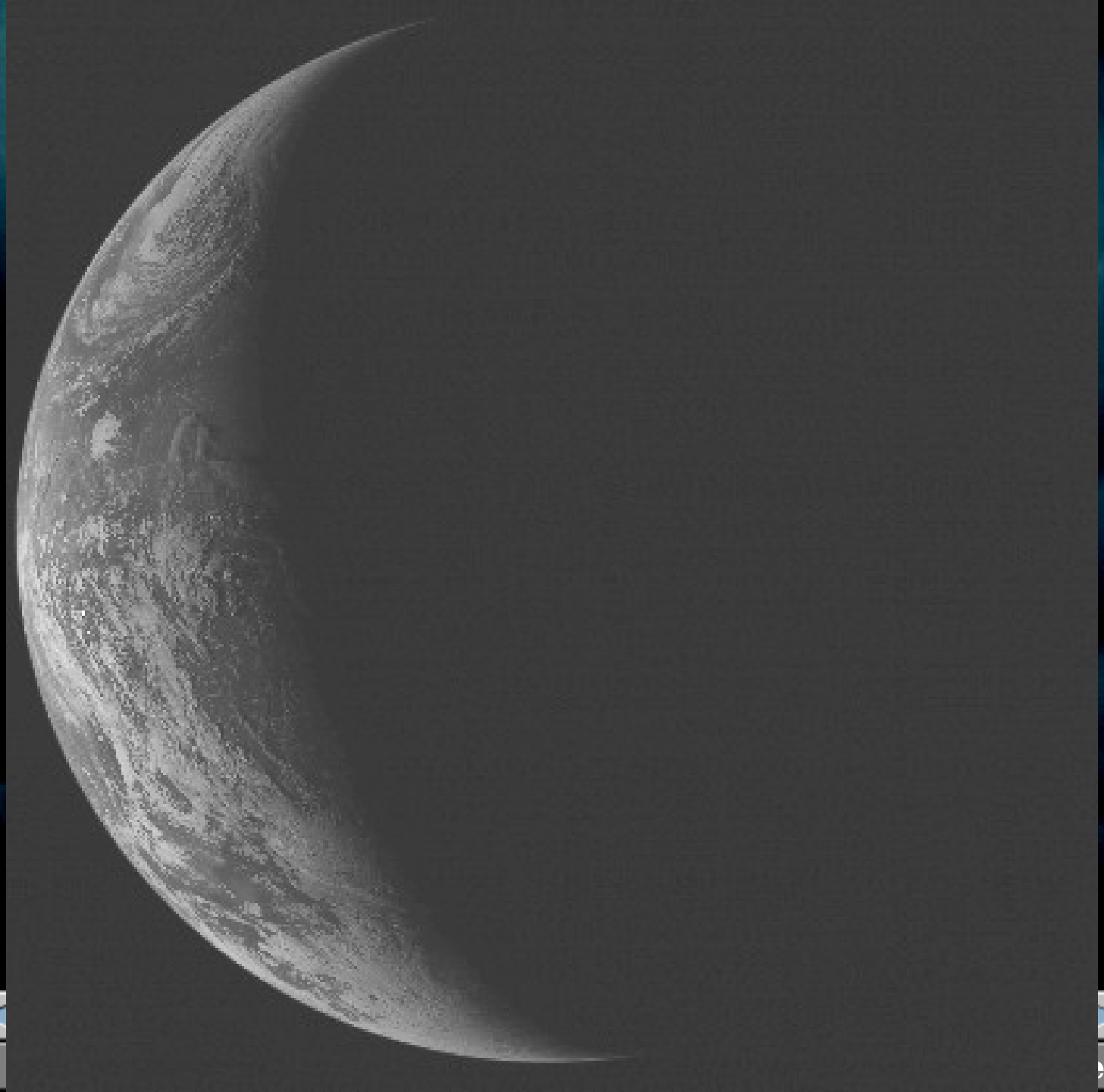






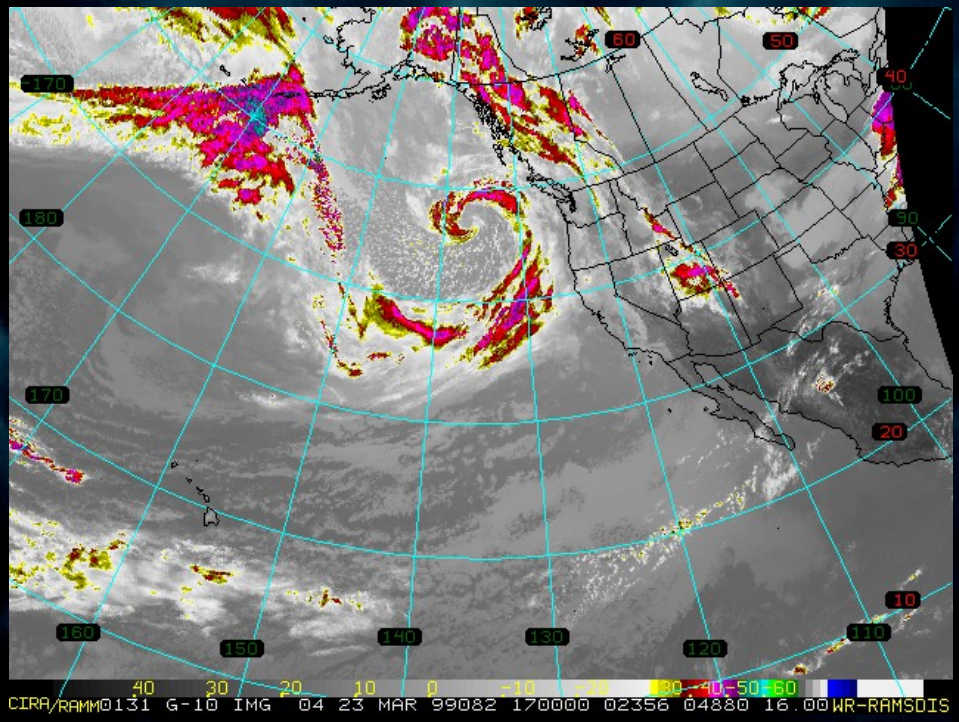






Satellite Imagery Viewing Considerations

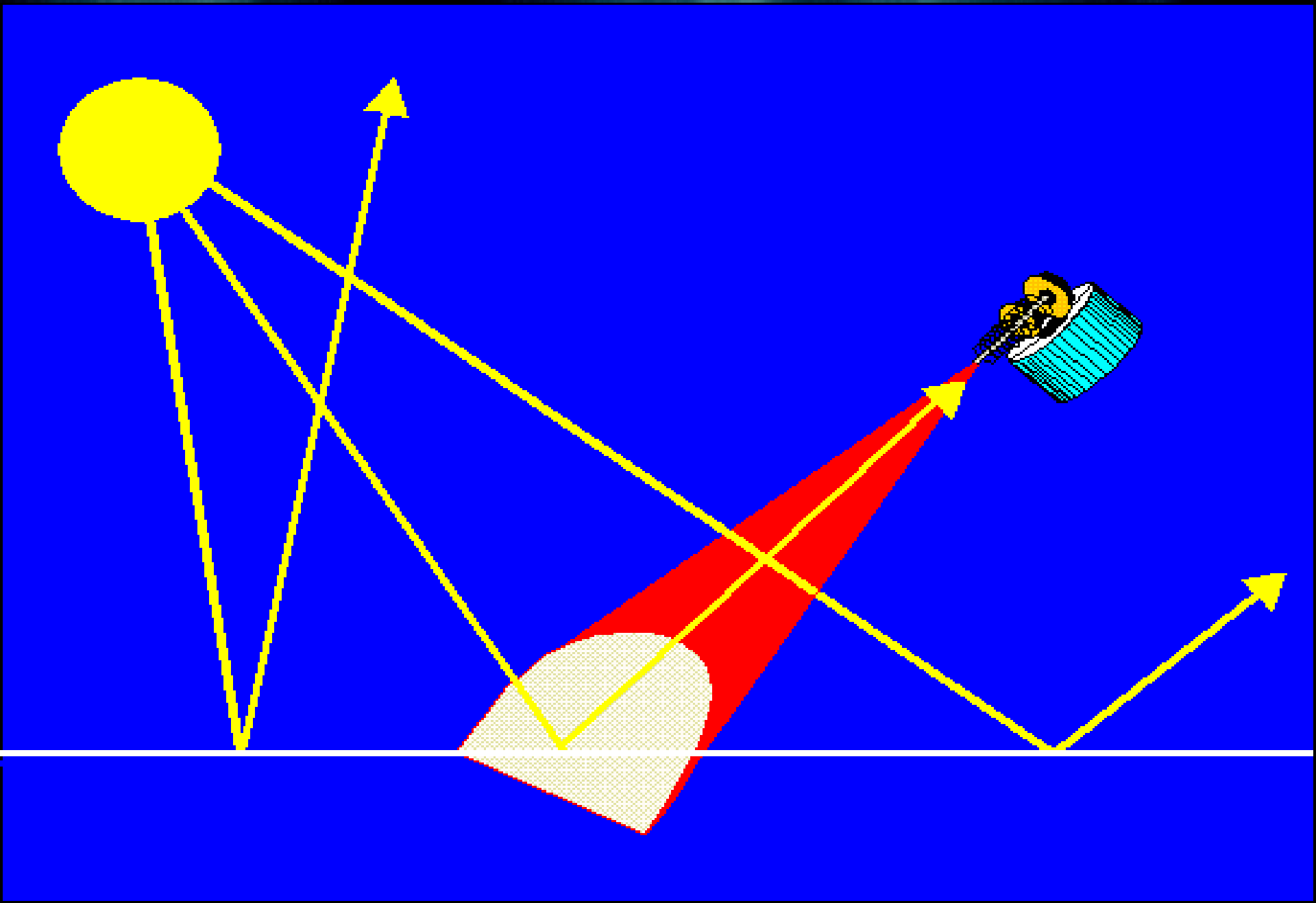
- Latitude
  - Elements at the same altitude Elements at the same altitude appear differently on infrared imagery
  - Northern features appear colder (higher)
  - Southern features appear warmer (lower)



Satellite Imagery Viewing Considerations

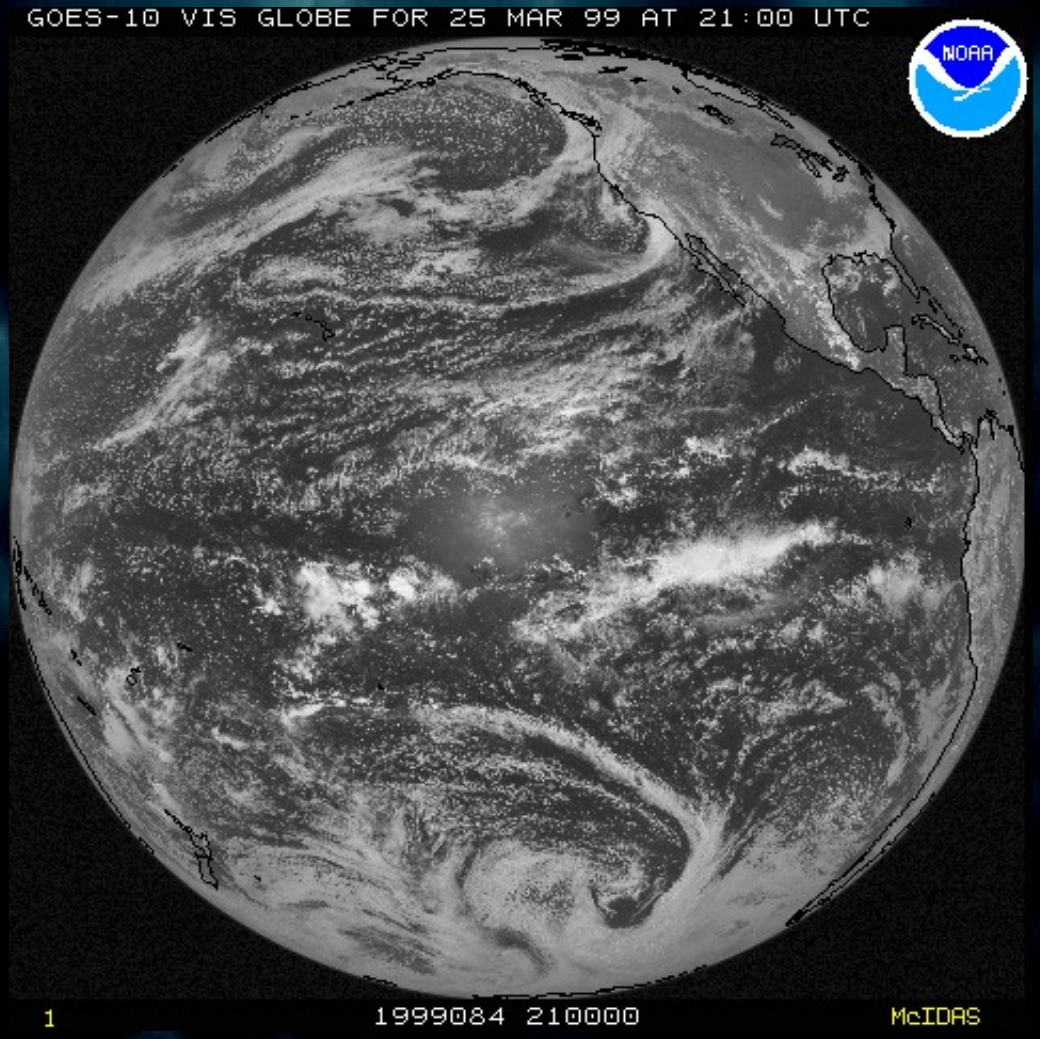
- Sun Glint
  - Occurs when the sun's rays reflect off water surfaces
  - Occurs when wind are light or calm
  - Occurs only on Visible imagery
  - Sun glint appears differently depending upon which satellite type is used

Sun glint



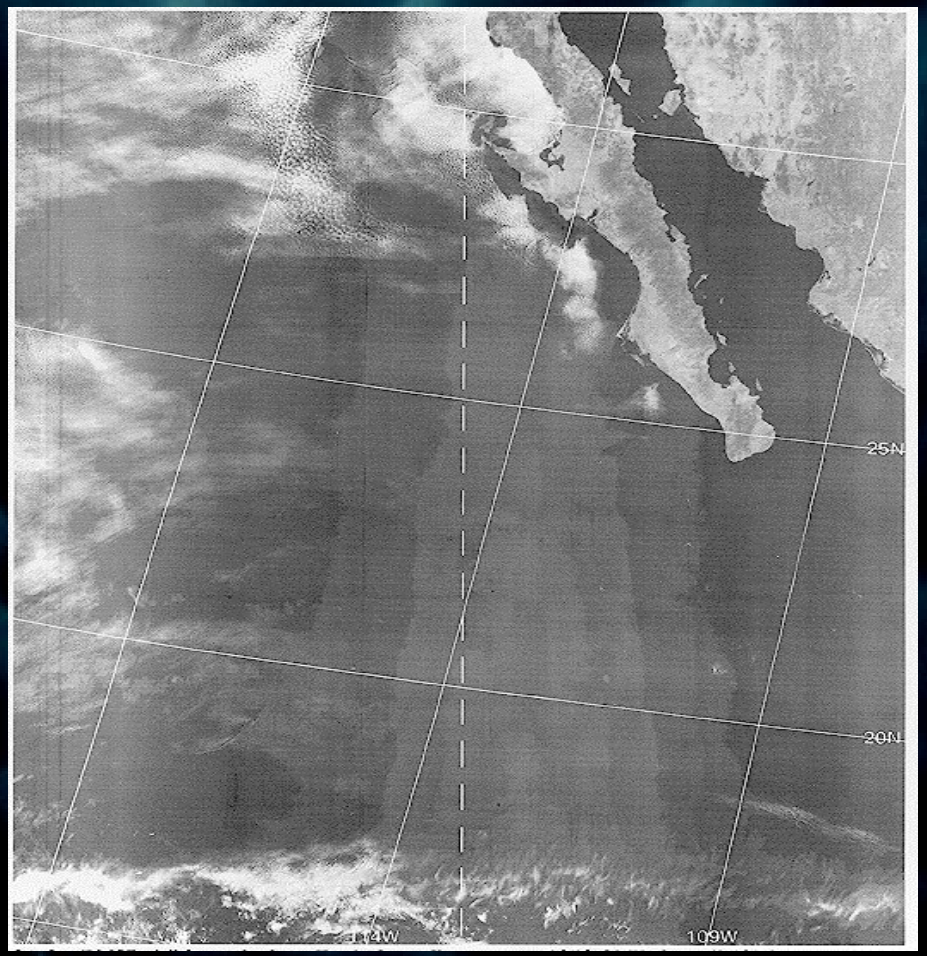
Sun glint

- Geostationary
  - Circular shape
  - Higher wind speeds result in more diffuse pattern

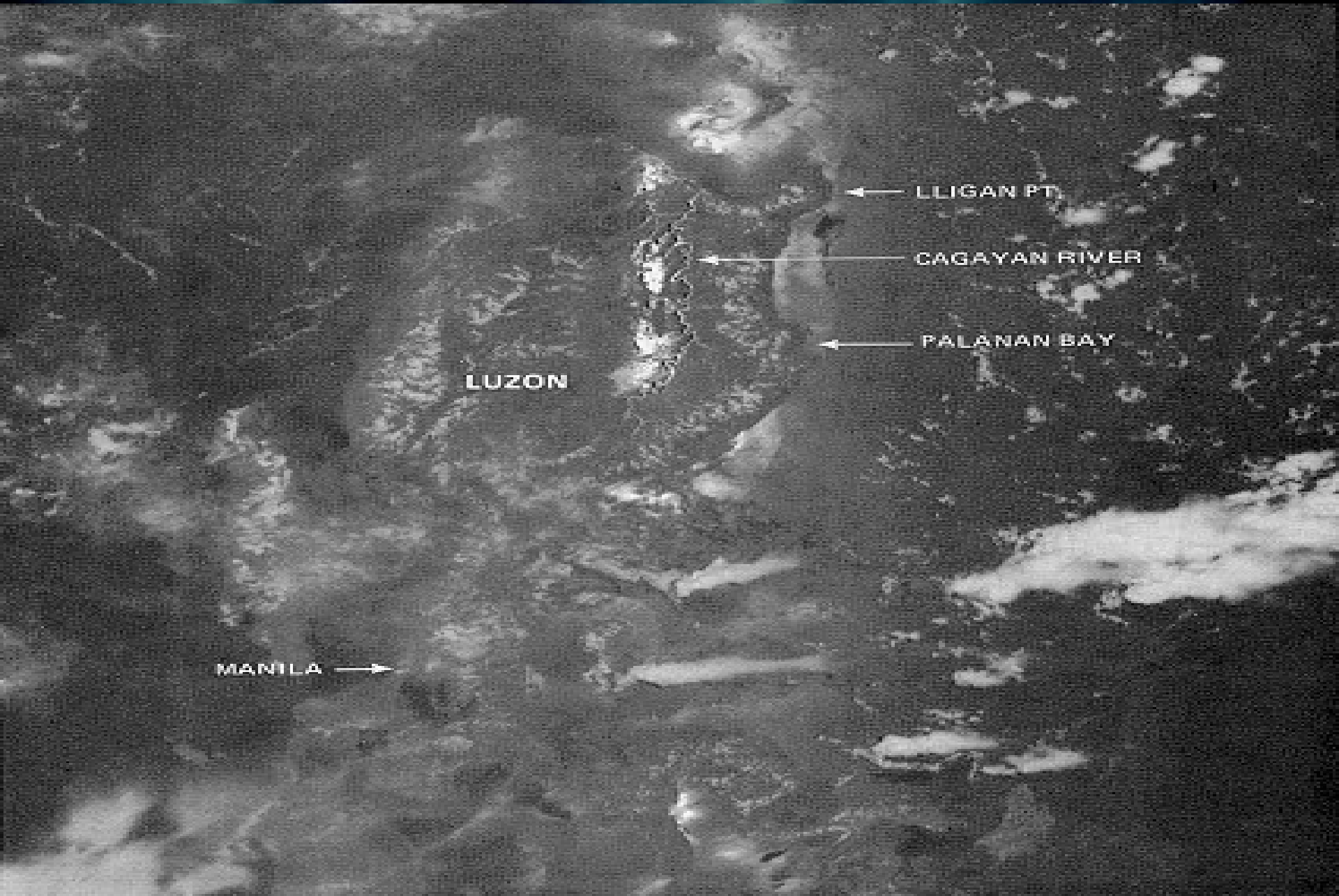


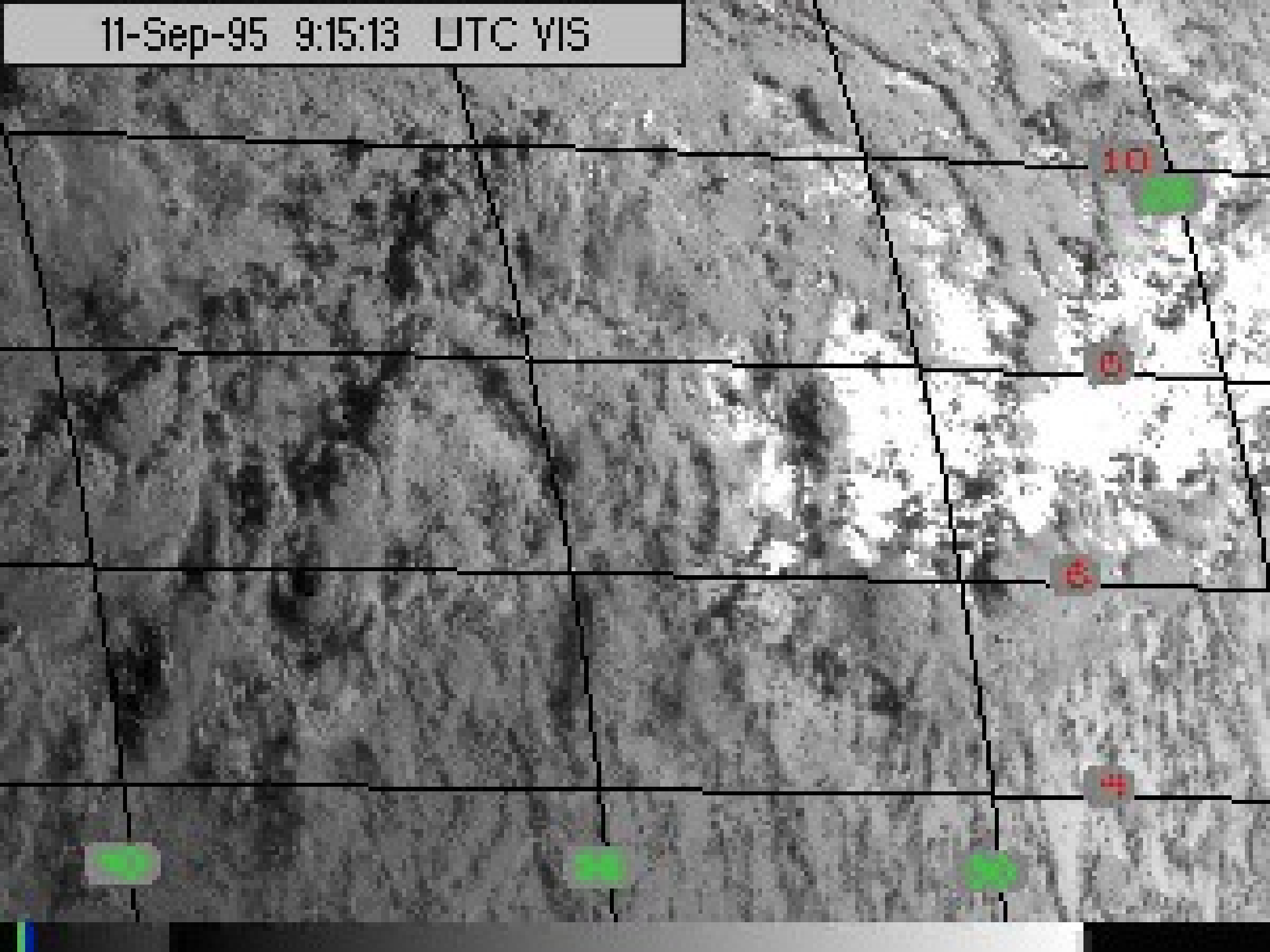
Sun glint

- Polar Orbiting
  - Linear shape extending from top to bottom of image
  - Higher wind speeds result in more diffuse pattern



Sun glint over land




11-Sep-95 9:15:13 UTC VIS

Review

- Satellite Imagery Viewing Considerations
  - Resolution
  - Attenuation
  - Contamination
  - Foreshortening
  - Gridding Errors
  - Sun Angle
  - Latitude
  - Sun Glint

- APPLICATION: Assign Review Exercise 1.

- EVALUATION: Administer and evaluate Appraisal 302a. Give the written Test at the end of the unit.